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Life Sciences Accomplishments

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COVER

A Handful of Emeralds by David K. Stone, oil, 48" x 46"
(NASA Art Program)

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Life Sciences Accomplishments

NASA Technical Memorandum 88177

SEPTEMBER 1985

NASA
National Aeronautics
and Space Administration

Scientific and Technical Information Branch

1985

Prepared for the NASA Office of Space Science and Applications Life Sciences Division

For further information: National Aeronautics and Space Administration
Life Sciences Division
Code EB
Washington, DC 20546

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Figure 1

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When the Space Shuttle *Columbia* entered orbit on April 12, 1981, an era of discovery and exploration began that changed the way we think about ourselves, the world we inhabit, and the universe that contains us. The Shuttle fleet has transformed us from ground-based spectators watching an intrepid few explore unknown regions into a spacefaring people with jobs to do and knowledge to gain beyond the confines of Earth.

Inspiration, drive, enthusiasm, and dedication are the tools our space program requires — and generates. Forged from the human spirit, these tools enable NASA to meet the challenge of space through rigorous scientific investigation and creative application of the resulting knowledge. It is in such endeavors that NASA's Life Sciences Division plays a vital role in charting our course in space.

Figure 2. *Columbia at Booster Separation*
NASA Artist: Bob McCall

As part of NASA's Office of Space Science and Applications, Life Sciences conducts one of the agency's largest programs of research on microgravity effects, sponsors advanced technology development for crew support systems in manned spacecraft, and is responsible for medical operations in support of all manned space flights. Its relationship to the Space Shuttle program is unique: the Life Sciences Division is simultaneously a major user of the Shuttle's laboratory facilities, a substantial contributor to spacecraft development, and a partner in its operation. In addition, the Division conducts a vigorous program of inquiry into the nature of life itself, exploring questions that can be answered best through experiments performed in space or by applying the tools offered by space technology.

Life Sciences has been a valuable participant in space exploration from the beginning of our nation's first space flights. It has evolved over the years to meet challenges and opportunities that have arisen as the space program matured. The Division has begun preparing for long-duration manned missions that will send teams of men and women from the Space Station outward to explore the solar system and carry our quest for knowledge to other worlds.

This report tells the story of some of Life Sciences' most recent accomplishments and reveals how the Division is laying a foundation for the challenges ahead.

B I Edelson

Burton I. Edelson
Associate Administrator
Office of Space Science and Applications
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Life Sciences Accomplishments
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Introduction

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"Real science exists, then, only from the moment when a phenomenon is accurately defined as to its nature and rigorously determined in relation to its material conditions; that is, when its law is known. Before that, we have only groping and empiricism. . . "

Claude Bernard

The goals and challenges of our nation's space efforts have always been woven tightly into the programmatic activities of the NASA Life Sciences Division. From its inception, the main charter of Life Sciences was to define biomedical requirements for the design and development of spacecraft systems and to participate in NASA's scientific exploration of the universe. As currently defined, the role of the Life Sciences Division is to:

1. Assure the health, well-being and productivity of all individuals who fly in space; and
2. Study the origin, evolution, and distribution of life in the universe.

The common thread between these two goals is understanding life and its adaptability to new environments. Explicit in the first goal is the development of biomedical foundations for human sustenance in space so engineers can translate knowledge gained from medical research into (Figure 3) safe and efficient spacecraft systems. Inherent in the second goal is the advancement of scientific knowledge of the nature of life in the universe: determining processes by which life originates; understanding the interaction and evolution of life and the physical environment; and identifying conditions existing beyond Earth that may be suitable for development of life.

Figure 3. *Shuttle-tethered Astronaut Dale A. Gardner on Flight 51-A (November 1984) to recover Westar VI Satellite NASA*

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The life sciences programs to achieve these goals are structured into projects and research units implemented at four major NASA field installations: the Lyndon B. Johnson Space Center, the Ames Research Center, the Kennedy Space Center, and the Jet Propulsion Laboratory. However, most NASA-sponsored life sciences research (over 60 percent) is conducted outside the agency at major universities throughout the United States.

Activities of the Division are administered from NASA Headquarters through three Branches: the Space Medicine Branch, the Biological Research Branch, and the Flight Programs Branch. Research conducted within each Branch of the Life Sciences Division represents a progression from basic studies through applied science to proof-of-concept demonstration programs, culminating in flight experiments and applications.

The programs in the Space Medicine Branch encompass activities in the following areas:

The **Operational Medicine Program** focuses on crew health and safety. This program conducts medical training of flight crews in onboard health and emergency practices; assures flight crew health monitoring and medical certification of their readiness for flight; develops spacecraft habitability and environmental monitoring requirements and medical procedures; conducts inflight clinical studies; and identifies as well as characterizes indices for health "norms" in space.

The **Biomedical Research Program** supports crew health activities by conducting research focused on developing medical or physical countermeasures to accelerate adaptation to the space environment and facilitate readaptation upon return to Earth. Medical issues associated with extravehicular activities, toxicology and microbiology of closed environments, radiation monitoring and protection, and advanced spacecraft life support systems are also addressed in this program.

The Biological Research Branch addresses more fundamental and basic issues of life processes and is subdivided into four broad areas of investigation:

The **Exobiology Program** explores conditions necessary for the development and evolution of life on Earth and throughout the universe; traces the path taken by atoms and molecules that comprise living organisms, from their origin in stars, through their accumulation into suitable planetary environments, to their incorporation into living species; handles issues related to planetary quarantine and conducts the search for life beyond Earth.

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The **Biospherics Research Program** examines the relationship between living and non-living components of Earth on a global scale; develops combined satellite monitoring and computer techniques to measure, model, and predict biologically important changes in the global ecosystem; and promotes research to apply the knowledge gained to solving terrestrial problems.

The **Gravitational Biology Program** explores, by inference from experiments conducted under weightless conditions, the role gravity plays in the evolution and development of life and examines the physiological adaptation of living species in space.

The **Controlled Ecological Life Support System Program (CELSS)** conducts biological systems and engineering research to develop bioregenerative life support systems for spacecraft, thus reducing the need to resupply food, water, and breathable atmosphere from Earth. Long-duration missions utilizing CELSS technology will permit manned exploration of the solar system.

In keeping with the Agency's policy of international cooperation, the Life Sciences Program frequently participates in joint endeavors with scientific colleagues from many nations as shown in Appendix 4. Over the years, joint experiments have been developed with foreign agencies such as the European Space Agency (ESA), Centre Nationale D'Etudes Spatiale (CNES), the Ministry of Science and Technology of the German Federal Republic (DFVLR). The Life Sciences Division has participated in Soviet Biosatellite experiments and has maintained close relationships with countries throughout the world to strengthen international cooperation in space biomedical research.

The Life Sciences Division is committed further to the development of a cadre of talented young people whose skills will be needed to answer future challenges in space biology and medicine. To meet this commitment, unique educational programs for undergraduate, graduate, and postgraduate students through formal training programs and preceptorships at field installations and universities have been developed.

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From Project Mercury to the Space Shuttle, (Figure 4) significant progress and contributions have been made by life sciences to overall NASA goals. Humans have been qualified for long-duration missions. The physiological time course of adaptation to space has been better characterized. Space is no longer a novel environment for physiologists and physicians. Medical standards for space flight have been relaxed. Continuous biotelemetry of flight crews is no longer required. Extended extravehicular activities (EVAs) are now commonplace because solutions to physiological constraints have been found.

From NASA's observatories and unmanned explorations of the solar system, significant accomplishments have been made in understanding the nature of environments extant on *other worlds* (Figure 5). We have detected biologically important and complex molecules light-years beyond Earth. Ground-based research has pushed back estimates of the time of appearance of life on Earth beyond 3.5 billion years ago, and forced a reevaluation of the phases of planetary evolution. New theories of the influence of astronomical events on the evolution of life have been advanced and are being tested. Ground-based and flight research have revealed the intricacy of life's relationship with gravity, and researchers are continuing to probe mechanisms by which gravity and life interact.

These advances were accomplished through rigorous research programs. Significant contributions were made by NASA and university research teams with the continuous help, observations, feedback, and execution of experiments in space by the astronaut corps.

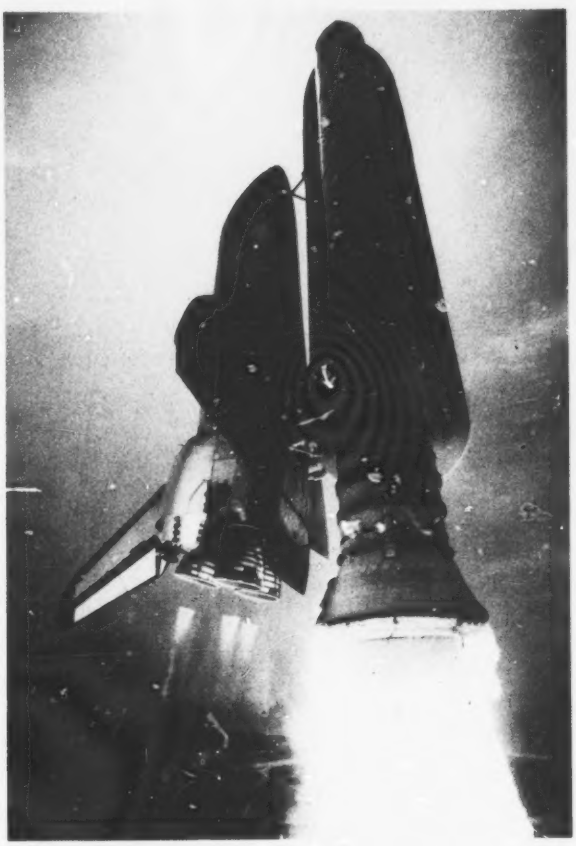

Figure 4. *Launch of the Space Shuttle*
NASA

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The future holds even greater promise. High quality investigations will be conducted in space to clarify the mechanisms of adaptation and develop sound, simple countermeasures and protective ensembles to make space more accessible than ever.

As we move forward, the search for life in the universe will become a more exciting research endeavor. Through the development of new, more powerful scanners, we will "listen" for signals from extraterrestrial intelligent life. Planetary missions launched during the next decade will allow a closer look at other environments where life might have existed or may one day abide. Finally, understanding Earth's biosphere will provide a "global model" that can be used to manage resources on our own planet more wisely.

Technology to benefit humankind has been a continuous spin-off from space life sciences research. Improved health care techniques, preventive medicine practices, and new medical monitoring and diagnostic instruments that combine increased accuracy with compactness and ease of operation have been or are being developed by the Division's ongoing research activities.

This is the first report of Life Sciences accomplishments, which encompasses primarily the 1983-1985 time period. Many life scientists at NASA Headquarters and at NASA field installations have contributed significantly to its preparation. I want to convey through this introduction my gratitude to all of them for helping to create this report and for the quality of the research conducted which made it a reality.

Arnauld E. Nicogossian
Director
Life Sciences Division, OSSA

Figure 5. *View from Mimas - based on Voyager photos of Saturn's Moon NASA Artist: Ron Miller*

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Life Sciences in Space

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From the beginning of time as we know it, precursors of life have been traveling in space. Life had its origins not in the primordial seas of the newly formed Earth, but in the cosmic burst of matter and energy that marked the beginning of the universe itself — the Big Bang. All life we know is made of star stuff, of atoms created millenia ago in nuclear furnaces of stars now long dead. Blown over galactic distances by solar winds and propelled by supernovae, these and other atoms gathered in the spiral arm of the Milky Way galaxy to form planets and moons and a medium-sized, nondescript star, our Sun.

In 1897, Samuel P. Langley, one of the fathers of modern aviation, a solar physicist, and an inventor of astronomical equipment, stated:

"It is now well understood that . . . every manifestation of life from that of the lowest vegetable form up through animal existence, to that of man, including all his works and industries, comes from the sun. . ."

That concept, the relationship of life and stars, dictates the current architecture of the NASA Life Sciences Division.

The predominant theme of the Life Sciences Program is a systems perspective of life's relationship to its environment (Figure 6). Although the study of life is as old as mankind, the ideas that there is an underlying unity encompassing all phenomena of life and that the origin and evolution of life are inextricably woven into the evolution of the planet

Figure 6. *Space Life Sciences into the Future*
NASA Artist: Rick Guidice

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itself are relatively recent developments. They are ideas in whose development NASA has played, and will continue to play, a critical role.

The organizational structure (Figure 7) of the Life Sciences Division encompasses exploration of the relationship of life and its environment on four scales. The largest scale is embodied in the Exobiology Program, which examines the origin and evolution of a living planet in relation to the evolving universe. The Biospherics Research Program investigates the interaction between living and non-living components of Earth on a planetary scale to understand how these components influence each other. Life's relationship with gravity, Earth's most constant and pervasive environmental pressure, is examined on the scale of individual organisms, through ground and flight studies in the Gravitational Biology Program. Of highest priority is the work conducted within the Biomedical Research Program and the Operational Medicine Program which constitutes the fourth scale of inquiry, the influence of the space environment on human health, safety, well-being, and productivity. The Division's Controlled Ecological Life Support System (CELSS) program blends the biomedical, gravitational biology, biospherics, and engineering expertise of the Division to develop life

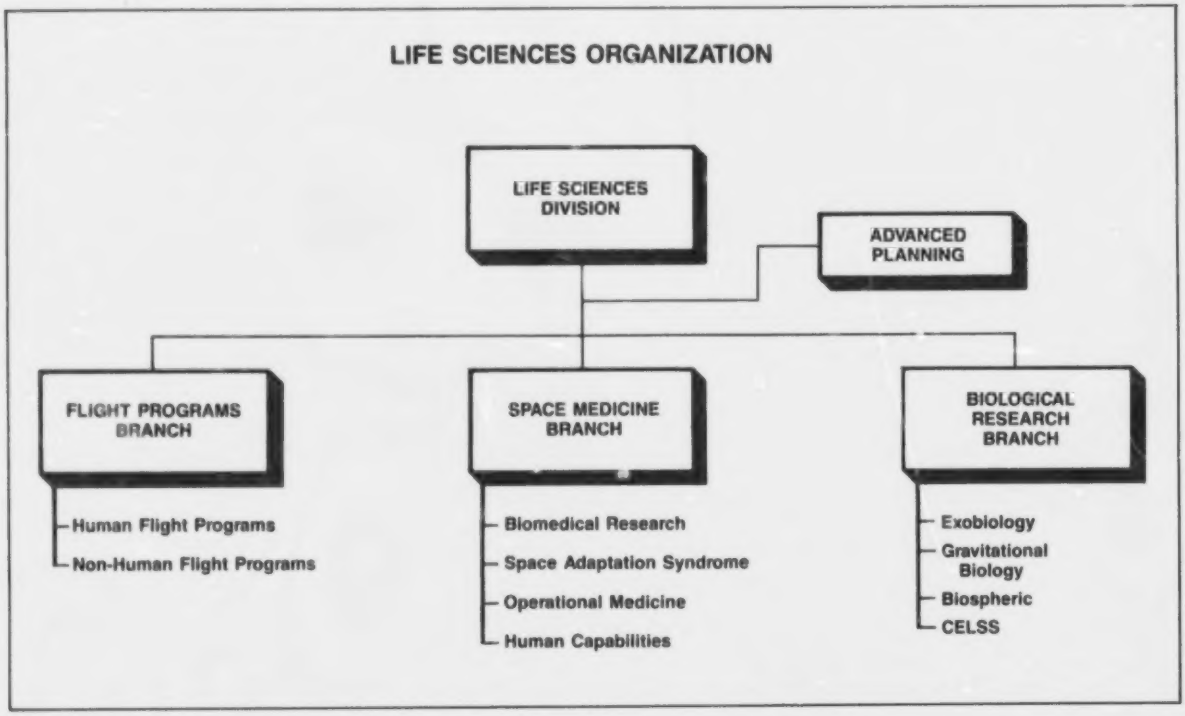

Figure 7. *Organization Chart · Life Sciences Division*

support systems for spacecraft that can process wastes and regenerate food, air, and water. Such systems are needed for long-duration, manned missions, such as solar system explorations or manned bases on other planets, where resupply of vital materials from Earth is impractical or impossible.

Each program described above requires access to space for research. However, because many materials (such as liquids) behave differently in the microgravity conditions of space than on earth, special laboratory equipment and experimental procedures must be specifically designed for use in space. In addition, flight experiments must fit within physical limits of the spacecraft and must allow as many experiments as possible to be conducted on each mission to achieve maximum scientific return. For these reasons, designing successful flight experiments requires a unique interaction between research scientists and flight engineers.

The Flight Programs Branch of the Life Sciences Division is responsible for developing equipment, facilities, expertise, and flight opportunities needed to assure the conduct of investigations in space. In addition, the Flight Program works to transfer knowledge gained from space flight into a form accessible and usable to the research community at large, and to develop new technologies and equipment for future flight and ground-based applications.

In recent years, life sciences investigations have been conducted aboard the Space Shuttle. In some cases, results of these investigations have confirmed classical or generally held hypotheses. However, other results have been startling and unexpected, requiring researchers to reexamine their assumptions about the intricate relationship between gravity and life.

These investigations were conducted on microorganisms, cell cultures, plants, animals, and humans. Although data are still being analyzed, a fascinating pattern is emerging, which indicates that all living organisms, from microbe to man, are influenced throughout their lives by gravity. The ability to accommodate and use gravity in physiological maintenance is built into our very cells, tissues, and organs in myriad overt and subtle ways. Only with the advent of space flight could this close relationship between gravity and life be revealed, because only in space can gravity be removed, thus allowing us to examine results of this change on living systems. The study of gravity's implications for health maintenance, reproduction, embryology, and development is in its infancy. However, space flight results are already opening new paths of research and offering tantalizing glimpses into the nature of life. We are becoming more confident that greater understanding will come in time, and that it will come from space.

In following chapters, the implications of NASA life sciences research will be presented: what we know, what we think we know, what this means for our future in space, and what we still have to learn to make space a permanent part of the human domain.

The Space Medicine Branch is responsible for assuring the health and safety of space crews and for defining human habitability and health maintenance requirements and procedures for spacecraft. These functions are carried out through two branch programs: the Operational Medicine Program, which applies clinical and preventive medicine practices to the unique conditions of space flight; and the Biomedical Research Program, which conducts supporting scientific investigations needed to refine and improve living conditions in space (Figure 8).

Figure 8. *The crew of STS-5 proves that humans can live and work successfully in space, thanks to countless hours of effort by physicians, scientists, engineers, and researchers who work to make space safe and accessible to man. Clockwise from top: Pilot Robert V. Overmeyer; Astronaut Joseph P. Allen; Commander Vance D. Brand; Astronaut William B. Lenoir advertise the completion of another successful Space Shuttle mission.*
NASA

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Operational Medicine Program

Protecting those who work in space has always been of paramount concern to NASA, and it is the Life Sciences Division's Operational Medicine Program that has the prime responsibility to assure the safety, health, and well-being of space crew. Much of the biomedical data needed to understand and develop countermeasures to the adverse effects of space flight on humans can only be validated through investigations conducted in space. To date, fewer than 250 individuals have experienced space flight. It is expected that within the next two decades, a much broader segment of the population will be spending varying amounts of time in space, and biomedical data on this new population's response to space flight is sparse, at present.

The Operational Medicine Program defines the medical selection and retention criteria for space crews. The space environment offers several features that are very attractive to science and industry, including low gravity, high vacuum, high-energy radiation, and an unobstructed view of the universe. The ability to use this environment has stimulated scientific and industrial communities to open innovative lines of research and development that require specialists who are not professional astronauts to work in space to achieve scientific and industrial goals. At the beginning of the Shuttle era, the Operational Medicine Program evaluated previous criteria for flight qualification of space crews and redesigned selection standards to meet the special needs and characteristics of the Shuttle program (Figure 9). In recognition of the requirement to refly experienced crews on subsequent missions, the Program also designed standards for retention of space crews. These have been recently updated and revised to accommodate the new class of crewmembers, Payload Specialists, scientific and technical experts in particular disciplines who are not professional astronauts. Evaluation of these criteria is an ongoing process. As the Shuttle program matures and Space Station plans emerge, criteria will evolve to reflect new insights gained and new challenges imposed.

Many qualities of the space environment that are valuable to scientific and industrial endeavors can pose special health risks to space crews. To monitor possible long-term medical consequences of space flight, the Operational Medicine Program has instituted longitudinal health surveillance of Shuttle crews. In this effort, space crews are medically monitored on a periodic basis throughout their lives, and data from these examinations are carefully analyzed to determine whether there are any long term effects from space flight. Longitudinal surveillance helps to establish the data base needed for improving future medical care in space and also provides early detection of potential health problems in crewmembers.

Space crews must be able to handle a variety of medical problems that may occur during flight. This presents special challenges.

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First, the complete sophisticated medical facilities characteristic of urban hospitals are inaccessible. Second, a spacecraft is a closed environment with limited volume available for an extensive medical equipment inventory. Third, microgravity affects even normal physiology in ways we do not yet fully understand. Therefore, a medical emergency in space may be even more difficult to manage than on Earth (Figure 10). Finally, many physical processes, such as the behavior of fluids, are different in space than on Earth. This necessitates development of special equipment and protocols for handling medical problems. The Operational Medicine Program has already developed routine and emergency medical procedures, equipment, and countermeasures for application on the Shuttle, and trains all space crews in their use on orbit. In addition, the Program conducts a vigorous development effort to continually improve, refine, and amplify the delivery of medical care in space.

The environment within and outside the spacecraft can present special medical problems. Consequently, the Operational Medicine Program has instituted a series of specific procedures to define and evaluate the effects of the space radiation environment during Shuttle flights and during Extra-Vehicular Activities (EVAs); establish toxicology standards and monitor toxic substances in the spacecraft; and establish microbiological standards and monitor the spacecraft's microbial environment during flight. In addition to these activities to assure spacecraft habitability, the Program conducts testing, certification, and quality control activities for food preparation and defines the criteria, procedures, and testing necessary to assure potable water throughout the mission.

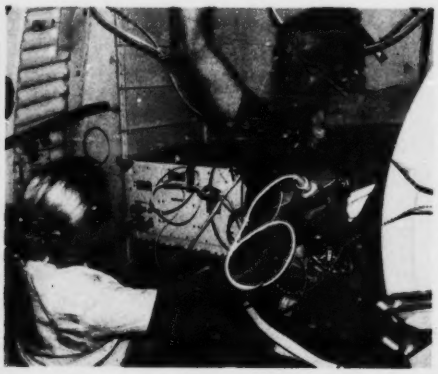

Figure 10. *Astronaut Rhea Seddon, a Co-Investigator on NASA-Johnson Space Center's American Flight Echocardiograph investigation, is shown making important measurements on Senator Jake Garn's heart during the first day of the STS 51-D mission.*
NASA

Figure 9. *Astronaut and former Skylab Astronaut Owen Garriott and Life Sciences Payload Specialist Byron Lichtenberg on Spacelab 1 conducting medical experiments.*
NASA

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One unique service offered by the Shuttle system requires space crews to conduct complex and strenuous EVAs for long periods of time. The EVA suit maintains a 4.3 pounds per square inch (psi) internal atmosphere, while the Shuttle's interior atmosphere was designed to accommodate 14.7 psi. This pressure change between suit and spacecraft increases risk of altitude decompression sickness, known more familiarly as the "bends". To meet safety requirements, the Operational Medicine Program instituted a high-priority research effort to minimize EVA risks. The criteria Operational Medicine established for design of these procedures provided the greatest possible protection for EVA crews with the least impact on Shuttle operations. As a result, these EVA procedures were tested and verified successfully on the STS-6 mission during March 1983, and have been in use ever since (Figure 11).

In anticipation of future combinations of cabin and space suit pressure differences in the Space Station and the Shuttle, a special pressure chamber developed at the Johnson Space Center is currently being tested and validated for use in designing new pre-EVA protocols to minimize risks and operational impacts even further.

As will be discussed in following sections, microgravity results in a number of physiological changes. To study, understand, and minimize adverse consequences of these changes, the Operational Medicine Program has developed and recently initiated routine countermeasure tests on Shuttle flights. One of these tests had an immediate benefit: drinking large quantities of an isotonic mixture of water and saline prior to landing led to a significant reduction in incidences of postflight orthostatic intolerance (microgravity-induced changes

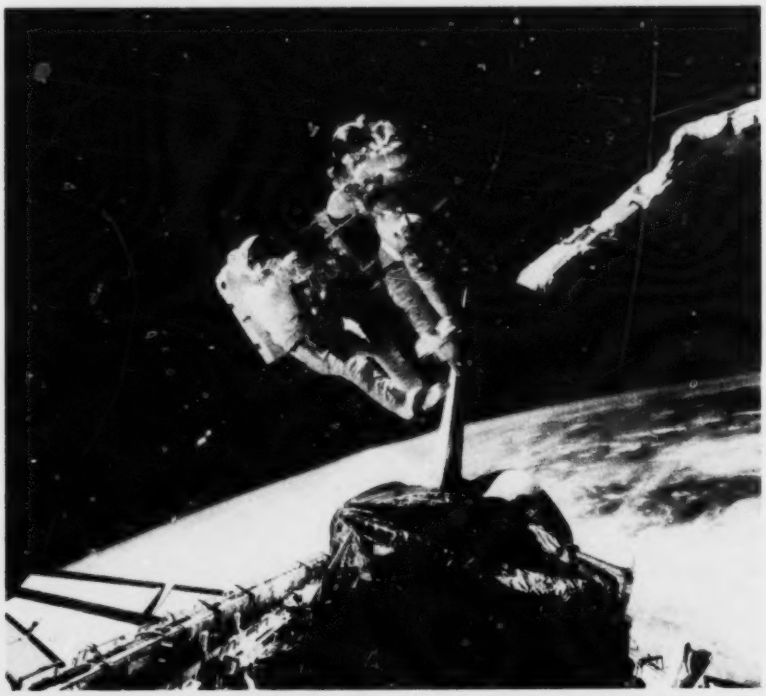

Figure 11. *Westar VI Satellite Retrieval — Astronauts Dale A. Gardner (left) and Joseph P. Allen IV on STS-51-A flight.*
NASA

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in the cardiovascular system that can cause fainting or dizziness when gravity is reimposed during re-entry and landing) (Figure 12). Another flight test conducted on Shuttle mission 51-D (April 1985) confirmed previous anecdotal information which suggested that drug effectiveness is reduced during space flight. This led to development of a research effort to characterize the extent of the problem and derive alternative approaches to drug treatment in orbit.

Part of the goal of the Operational Medicine Program is to enhance crew productivity. However, medical problems can affect space crew operations. To bring the ablest medical and scientific research talent to bear in solving these problems, the Space Medicine Branch established the Space Biomedical Research Institute in March 1984. At present, the Institute concentrates on solving the problem of space motion sickness through clinical investigations and space flight experiments to determine the causes and treatments of this condition.

The Operational Medicine Program also conducts tests on parabolic flights in KC-135 aircraft to evaluate gravity non-dependent technologies and procedures for flight medical care. These tests are part of the continuous effort to refine and improve medical procedures for space flight applications. In addition, two major complementary goals are being accomplished with advanced technology development in the areas of man-systems integration and man-machine engineering. Tools are being developed to design and engineer better equipment, vehicles, and operations for inflight crews and to enhance crew productivity. In addition, during development of these tools, ground and inflight measurements are being made to improve quantification of human capabilities and performance. These measurements are then used to build computer models of human operations. Through knowledge gained on human performance requirements, the Operational Medicine Program will help achieve the synergy of crew, vehicle, and operations needed to improve crew health and safety in space.

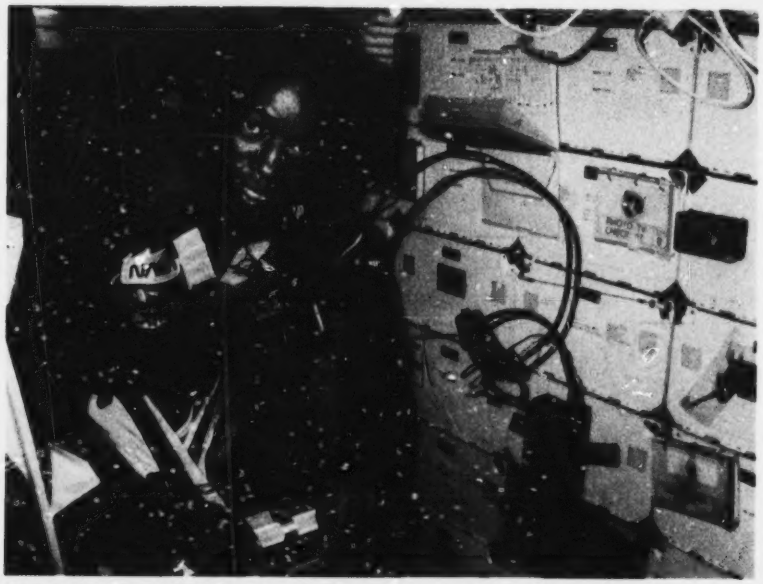

Figure 12. *On the STS-8 mission, Astronaut Guion S. Bluford uses the treadmill exercise device in a medical test designed to evaluate the effects of space flight on the heart and circulatory system.*
NASA

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Engineering tools being developed include an interactive crew station design system (PLAID) which incorporates a man-modeling system (TEMPUS). PLAID and TEMPUS employ sophisticated computer graphics to place accurate models of human bodies in modeled work stations as shown in Figure 13. The capability to produce computer-generated animated scenarios automatically from flight crew procedures checklists is also being developed as shown in Figure 14. These scenarios will help identify crew procedures and analyze crew activities to optimize performance, assess vehicle layout for traffic patterns, and simulate inflight operations easily and economically.

Figure 13. *PLAID/TEMPUS System*

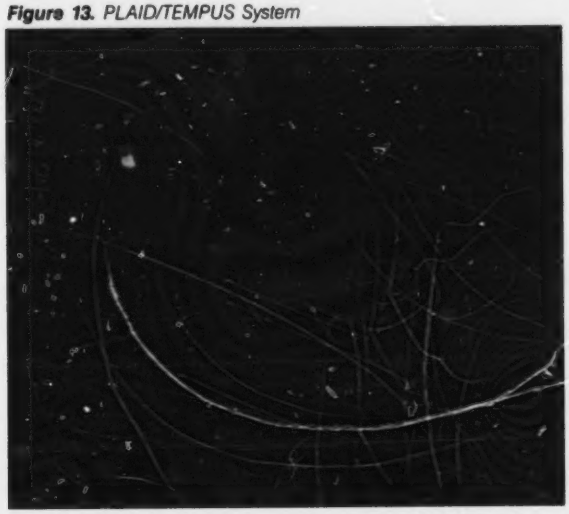
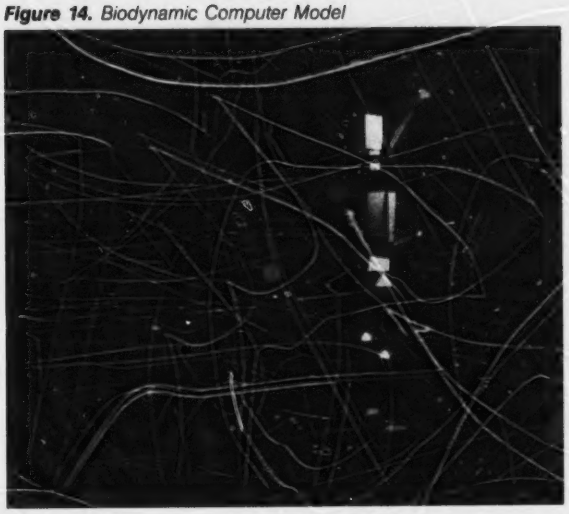


Figure 14. *Biodynamic Computer Model*



In keeping with its responsibility to define habitability and health maintenance requirements for future long-duration manned missions, the Operational Medicine Program has developed specifications for a Space Station Health Maintenance Facility. The Health Maintenance Facility (HMF) will incorporate inflight preventive medicine technologies and equipment, diagnostic facilities, and therapeutic capabilities and equipment. Inflight medical capabilities required for Space Station will be a function of the number of space crew working in the Space Station, the type of work being conducted, different medical scenarios that could occur, and the lack of an immediate rescue capability.

The Operational Medicine Program draws heavily on insights gained from supporting research conducted in the Biomedical Research Program of the Space Medicine Branch. This research has not only helped to improve medical care in space, but also revealed some fascinating aspects of human evolution in the gravity environment of Earth. The next section of this report describes activities of the Biomedical Research Program and presents significant new insights into the physiological and psychological challenges of space.

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Gravity has shaped life on Earth. Our internal and external forms have adapted to gravity's demands in countless subtle ways through centuries of evolution. So pervasive and constant is its influence and so completely did life adapt to it, that gravity's role in directing biological processes was largely ignored in life sciences research until the space program underlined its importance. However, the interdependence within a living body is of such complexity that changing one organ or system generally produces complex ripple effects on other organs or systems. These effects extend throughout the body, making causes-and-effect relationships difficult to discern. For this reason, even after twenty-five years of manned space travel, many biological and biomedical responses to the space environment remain unknown.

Data already collected during space flight demonstrate that humans and other animals undergo profound (but thus far reversible) physiological changes in microgravity. These changes occur during two phases: an acute phase, extending through the first hours and days in space; and an adaptive phase, which may span many days or weeks. Disturbances that extend throughout the body seem to be caused by three major physiological changes to weightlessness: the shift of blood from the lower part of the body to the upper; (Figure 15) the inactivity or unloading of muscle and bone; and disturbances caused by unfamiliar sensory inputs. At this time, it is not known how long space crews can remain in space without reaching a physiological point of no return. Thus, the major goal of the Biomedical Research Program is to determine

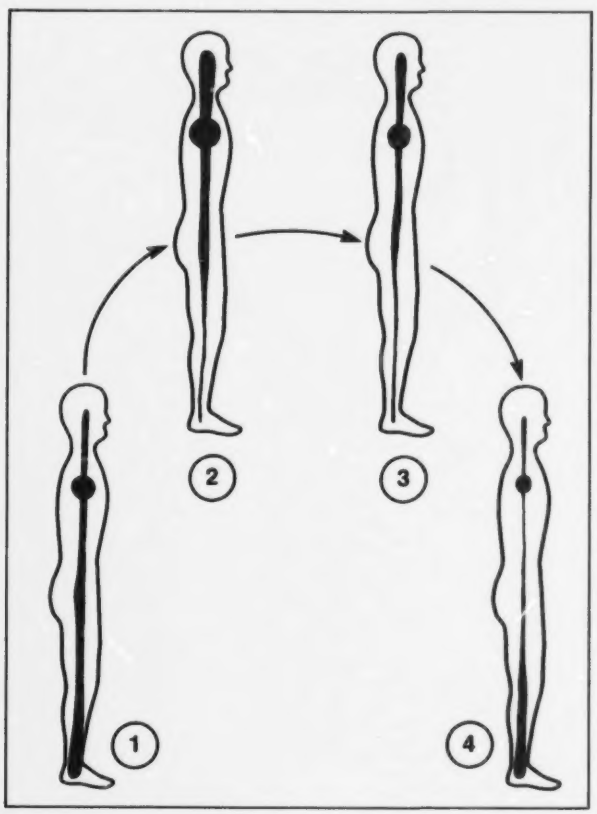

Figure 15. *The fluids in the body from Earth to space and back again. Part 1 shows the normal distribution of body fluids on Earth prior to space flight. Part 2 shows what happens immediately after entry into space (acute phase): fluids shift headward and the central circulatory system becomes engorged, delivering an increased amount of blood to the heart; head fullness and nasal congestion are experienced, the upper veins become distended, and the leg veins empty and contract inward. Part 3 shows what happens once the body has adapted to living in the near weightlessness of space (adaptive phase); blood volume is decreased, which unburdens the central circulation and the blood vessels in the head and neck, and there is a slight increase in the volume of blood in the leg veins. Part 4 shows the body's immediate response when it encounters one gravity after it has adapted to space flight (postflight): the decreased blood volume of the body coupled with increased blood vessel capacity in the lower body produces lightheadedness and dizziness in some people because blood is being drawn from the head to the feet.*

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consequences of the body's response to space; elucidate underlying mechanisms that direct these responses; and develop countermeasures to minimize adverse consequences.

In pusuit of these goals, the Biomedical Research Program conducts research in the following areas: cardiovascular physiology (heart and circulatory system), bone physiology, muscle atrophy, neurophysiology (brain and nervous system), radiobiology (radiation effects), psychology, and hematology/immunology (blood and immune system), general metabolic responses, and nutritional requirements.

Cardiovascular changes occur during space flight when gravity's force is removed from the liquids, organs, and support structures of the body. Blood circulating through the body is redistributed headward: leg veins empty and the body fluids become more centrally distributed. Within days, the total circulating blood volume is reduced, and the heart shrinks in size. From Skylab experiments, it was apparent that the cardiovascular regulatory system adapts to the sudden fluid shift into the upper body by removing apparent excess water via the kidneys. This has significant medical implications. For example, if an astronaut is injured and suffers a significant blood loss, he or she may be at a greater risk of shock because the body's blood volume has already been reduced by adaptation to weightlessness.

To understand better how the human cardiovascular system compensates for weightlessness, researchers conducted bedrest studies which simulate microgravity. Those studies showed transient increases in pressure in the right side of the heart, excessive discharge of urine, and an increase in the volume of the left side of the heart. These types of changes are thought to contribute to postflight orthostatic intolerance (a condition seen in all returning space crews that causes dizziness or fainting and difficulty in maintaining an upright posture when gravity is reimposed following adaptation to weightlessness). The bedrest studies offered a promising countermeasure to this condition. A carbohydrate diet combined with several therapeutic drugs protected four out of seven known fainters upon standing immediately after bedrest. Other simulation studies helped characterize the extent of cardiovascular changes. Results from these studies suggest that exercise capacity may return to normal after successive Shuttle flights separated by only two weeks. This finding is significant because Shuttle launches will soon be scheduled on a monthly basis and demand for experienced space crews will increase.

Physiologic alterations produced in the heart during space flight were identified using an ultrasound scanner to study space crews' hearts before, during, and after Shuttle flights. Preliminary

data taken from four crewmembers inflight suggest that major cardiovascular adjustments (Figure 16) take place within the first day or so in space: the size of the left side of the heart (which propels the blood through the circulatory system) reaches its maximum, as does the volume of blood it pumps. The right side of the heart (which collects blood returning from the rest of the body) is apparently already smaller than during pre-flight — just the opposite of the hypothesized change. By the second day in orbit, the entire heart becomes smaller than it was preflight, and subsequent changes in the cardiovascular system progress more slowly than on the first day. Postflight data indicate that the ultimate reduction in left heart volume imposed by short-term space flight remained uncorrected for at least a week after the mission, and that possible decreases in heart mass might accompany this change without reduction in overall heart performance. From these initial results, investigators concluded that the cardiovascular system can adjust quickly to fluid shifts and blood volume loss after space flight. However, long-term adaptation of the cardiovascular system, and its function during emergency operations when normal postflight precautions cannot be initiated, are still under investigation.

Figure 16. *Astronaut Rhea Seddon, a Co-Investigator on NASA-Johnson Space Center's American Flight Echocardiograph investigation, is shown making an ultrasound scan of Astronaut Jeff Hoffman's heart during the STS-51-D mission April 1985.*
NASA

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The cardiovascular system shows immediate changes on encountering weightlessness. Other body systems react more slowly, but may produce more serious effects. When considering the physiology of the skeletal system, for example, we are confronted with a structure designed for terrestrial use only. On Earth, maintaining a healthy skeleton depends partly on gravity and on strain applied to bones by the muscles during normal daily activities. When effects of gravity are removed, as during space missions or with bedridden and paralyzed individuals, bone minerals (calcium and phosphorus) and their supporting skeletal matrix are slowly lost. This occurs because bone resorption (the movement of bone material out of the skeleton and into the bloodstream) occurs faster than bone formation. During space flight, bone loss is believed to occur in areas of the body that provide support against the force of gravity — the spine and leg bones. One medical consequence of bone loss is increased risk of skeletal fracture and kidney stone formation, which makes developing countermeasures to space-flight-induced bone demineralization a research effort of the highest priority.

In biomedical studies conducted under simulated weightlessness, non-human primates showed 22 percent bone mineral losses in their leg bones in 7 months. Compact bone found in the shaft was restored within 2 to 3 years, but spongy bone was not completely replaced, even after 40 months of recovery. In weightless simulation studies conducted on humans, total body calcium was lost at a rate of about 0.5 percent per month, and the retention of phosphorus was also decreased. This study was conducted on healthy men who volunteered to stay in bed continuously for 9 months. Results of these investigations emphasizes that repeated exposures or prolonged exposure to weightlessness will probably lead to continuous bone demineralization.

Many physical measures were used to prevent demineralization during weightlessness simulations, including exercise with a variety of equipment, impacting the bottom of the heel to send "gravity-like" signals to the skeleton, and applying negative atmospheric pressure to the lower body to simulate the effect of gravity on body fluids. The physical therapies tested were not effective in preventing negative calcium balance in the body, and results suggest that at least 4 hours of walking per day is necessary to prevent skeletal atrophy. However, dietary supplements of calcium and phosphorus were partially effective in increasing calcium retention. Unfortunately, a high mineral diet can serve as only a partial countermeasure to bone loss resulting from space flight.

Developing countermeasures to space-flight-induced changes in the skeletal system remains one of the greatest challenges to the Biomedical Research Program, because of bone's heavy dependency on gravity to maintain normal physiological integrity (Figure 17). For similar reasons, the problem of muscle atrophy also remains unsolved though recent work shows some promising new avenues for development.

During the 28-, 59-, and 84-day Skylab missions, astronauts experienced up to a 20 percent reduction in leg strength with an 8 to 12 percent reduction in leg volume. Exercise, including treadmill use, reduced the severity of muscle loss, although these methods were not entirely effective.

Experiments conducted in simulated weightless environments investigated use of stretching and electrical stimulation to prevent muscle atrophy due to inactivity. In these studies, muscle atrophy was prevented by stretching the muscles in an extended position. When stretching was combined with electrical stimulation, there was an increase in size of muscle fibers. However, since these models simulate only some of the effects of weightlessness, the use of exercise, growth factors, passive stretching, and electrical stimulation must be tested further in space.

A new technique to investigate human physiology, called magnetic resonance imaging, is being used by the Biomedical Research Program. This safe and non-invasive technique allows researchers to study changes in atrophied muscle as well as investigate some of the other physiological changes that result from weightlessness simulations and space flight (Figure 18).

In terms of operational problems, one of the most

Figure 17. *Skylab 4 Astronaut Gerald P. Carr lifts Astronaut William R. Pogue on one finger, demonstrating the unloading effect of microgravity on weights, muscles, and bones.*
NASA

Figure 18. *STS-8 Astronaut Dr. William Thornton undergoes self-conducted medical testing onboard Challenger during the August 1983 flight to monitor a variety of body systems affected by space flight.*

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annoying and elusive physiological problems encountered during space flight is space motion sickness. After initial entry into weightlessness, about half of all space crews, including Shuttle crews, experience lethargy, nausea, or vomiting for 3 or 4 days. After this, they remain symptom-free. The unpleasant and possibly debilitating symptoms can reduce crew productivity and affect their physical well-being.

Space motion sickness is a neurophysiological problem resulting from conflicting signals sent by the otoliths (balancing organs of the inner ear), the eyes, and muscle sensors. In weightlessness, the eyes may tell the brain that the body is motionless, while the inner ear is signaling the brain that the body is falling.

Studies conducted at NASA Ames Research Center suggest that training space crew in biofeedback techniques prior to flight may be useful in countering some symptoms of space motion sickness. This approach may be especially helpful in relieving some symptoms not responsive to drug treatments.

Research conducted to understand and alleviate this problem included experiments carried out by the Space Biomedical Research Institute (SBRI) before and after several Shuttle missions that employed a special parallel swing. This device was used to compare returning space crews' responses to linear and rolling movements with those obtained before flight. SBRI investigators found that one astronaut was nearly three times less sensitive to motion after the flight, while other subjects showed no change in motion detection sensitivity. However, in some cases, rolling motion was preceived primarily as linear motion. These results confirm that sensory signals from the otolith organs are reinterpreted. That is, during flight all signals from the otolith organ in the inner ear, which senses gravity and linear acceleration, come to be interpreted by the brain as linear motion.

On a more basic level, NASA researchers traced previously unknown pathways between nerve fibers from the organs of the inner ear to the spinal cord and to brain areas responsible for control of balance. Other researchers provided evidence that a substance in cerebrospinal fluid may trigger vomiting, because symptoms were prevented from appearing when the flow of spinal fluid to the zone in the brain which controls vomiting was blocked.

Recently, a unique facility was developed at Ames Research Center called the Vestibular Research Facility. NASA scientists there use a special centrifuge to record eye movements and electrophysiological signals under hypergravity conditions to clarify how gravity affects inner ear functions. This Facility provides an important tool that will help advance our understanding of the mechanisms that underlie space motion sickness.

Although the problems described above are of considerable medical concern, perhaps the most significant limiting factor on long-term manned space missions is the radiation hazard. Radiobiology studies over nearly a century show that ionizing radiation, even at fairly low doses and dose rates, can induce cancer: the higher the dose, the greater the probability of induction. High doses at high dose-rates in space, such as from an anomalously large solar flare, can cause nausea, vomiting, diarrhea, and eventually death. The radiation from such events is not a critical factor for Shuttle flights in low-inclination, low-altitude orbits where the Earth's magnetic field shields the spacecraft. However, in polar orbits, any EVA (Figure 19) would have to be terminated during a large solar flare and the crew would have to seek shelter in the most heavily shielded part of the Orbiter (the airlock) or in a specially shielded shelter in a polar-orbiting Space Station. Exposure under these conditions may lead to curtailment of an astronaut's career to reduce cancer risk, although it would probably not be immediately life threatening. NASA relies on the radiobiological community as a whole for studies to provide assessments of radiological health risks for near-Earth orbits.

Some components of space radiation, such as galactic cosmic radiation or highly charged and energetic (HZE) particles that easily penetrate matter, make it impractical to provide enough shielding to

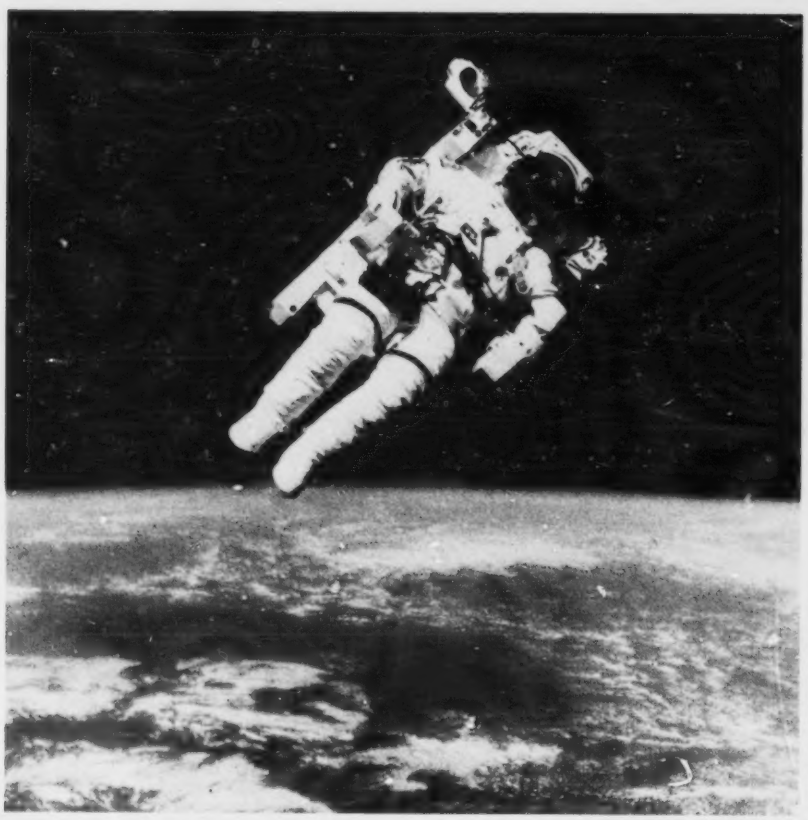

Figure 19. *Astronaut Bruce McCandless II on the STS-41-B mission (February 1984). This spacewalk represented the first use of the nitrogen-propelled, hand-controlled manned maneuvering unit (MMU).*
NASA

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eliminate crew risk entirely. Fortunately, HZE particles are not numerous in polar orbits or even outside the Earth's protective magnetic field. But exposure to them will occur in interplanetary missions, such as those to the Moon or Mars. A major unkown is the relative radiation damage produced in biological systems by HZE particles.

NASA-supported studies have provided evidence suggesting that large numbers of cells can be adversely affected by a single HZE particle. Other evidence suggests that a given dose of HZE particles is 20 to 40 times more effective than a given dose of x-rays in producing cancerous changes in cells. NASA-supported researchers have recently demonstrated that radiation effects are more deleterious toward the end of the life span than at the time initial damage occurs. In addition, late effects produced by moderate doses of HZE particles depend on the age of the subject when irradiated. These phenomena are reflected in premature aging, hair loss, brain damage, and progression of cataracts.

Studies partially funded by NASA and conducted at the Lawrence Berkeley Laboratory support the recent reevaluation of traditional methods for assessing cancer risks from exposures to densely ionizing radiation. Densely ionizing radiation produces more biological damage per unit of

Figure 20. *Life Sciences Payload Specialists Millie Fulford (left) and Drew Gaffney (right) undergo training for flight biomedical studies.*
NASA

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absorbed energy than does sparsely ionizing radiation (e.g., x-rays).

For several decades, researchers thought that risk from radiation was related to the degree to which energy is deposited per unit track length — called the linear energy transfer (LET). Now, studies show that ions with the same LET, but different charges and velocities, have different relative biological effectiveness. Other experiments show that damage (produced by heavy ions) is repaired little, if at all. These findings indicate that the structure of the track made by an ion passing through a cell plays a role in producing cancer-causing damage. These studies add to our basic understanding of the biophysics of radiation-induced cancer, and are influencing the establishment of radiation protection standards for occupational exposures on Earth as well as in space.

Part of the difficulty in understanding radiation effects in space relates to space flight's effects on normal cell physiology. Many changes occur in the distribution, function, and production of active substances by blood cells during space flight (Figure 20). A significant reduction in the number of circulating red cells, lymphocytes (cells responsible for immune competence), and certain other blood cell components is typically reported for human crews and test animals following space flight. At the same time, there is invariably a postflight increase in numbers of white cells of the type that collect in response to infections. In addition, postflight decreases in the ability of immune-competent cells to respond appropriately to foreign substances or to produce lymphokines (substances which control cell activity) are also nearly universal.

The loss of red cells, often referred to as space flight anemia, could be caused by one or a combination of the following events: a decrease in the ability of the bone marrow to produce cells properly; an increased destruction of red cells within the body, or by movement of red cells out of the circulatory system. All these phenomena have medical significance and are being thoroughly studied.

The ability of immune-competent cells to recognize and respond to challenge by foreign substances is generally depressed postflight, and has become more severe as inflight stress increases. Immune cells cultured in space lost almost all ability to respond to foreign challenge. Recent studies with cells from Shuttle astronauts indicated that this phenomenon may derive from a loss of internal control resulting from severe changes in blood cell populations during flight. These findings are of considerable medical interest as the cells involved are responsible for protection against infectious disease and for immune surveillance against harmful cell growth — such as radiation-induced cancer.

Studies conducted with two Soviet space laboratory crews have demonstrated increased

production of interferon during flight with both a decreased interferon production and a decrease in protective cell activity following flight. On the other hand, mice tested under simulated weightless conditions showed significantly reduced interferon production. An inhibition of interferon induction in space crew could allow occurrence of viral infections to which they would normally be resistant. Reduction in the protective cell activity could result in a reduced ability to cope with abnormal or cancerous cell growth, one of the most important activities of immune cells.

All research previously discussed dealt with physiological responses to the space environment. However, space flight operations also require flight crews to maintain high levels of performance in a dangerous and stressful environment. Space crew must be able to adjust successfully to stresses of weightlessness, confinement, crowding, and isolation from familiar terrestrial surroundings. Consequently, there is a need to understand basic principles that govern group dynamics and motivation under these circumstances, so that necessary crew performance may be improved.

The character of space missions is changing. Early Shuttle flights were relatively short in length and were flown by small crews of highly selected individuals from similar backgrounds. Space Station missions now being planned will involve larger and more heterogenous crews with longer stays on orbit (about 90 days). With this in mind, NASA scientists evaluated how different groups of individuals adapted to being isolated and confined for 105 days. Initially, test subjects exhibited high levels of anxiety with elevated levels of stress hormones and increased heart rates. One group of less compatible members preferred activities that involved personal enrichment or did not require lengthy social contact. The group with more compatible members preferred activities requiring interaction over activities of personal enrichment.

These results demonstrate that proper consideration of group dynamics is crucial to the success of future long-duration missions. Space Station modules should be designed to promote crew interaction without crowding. Crew selection and training should promote social compatibility as well as proper technical expertise.

Although problems mentioned in this section are of medical concern, none has ever prevented space crew from accomplishing astonishing feats of ingenuity and performance (Figure 21). It is likely that human capability in space will continue to grow as we become more familiar with space environment. We are confident that the new findings described in this section will spur development of even better countermeasures to minimize risks and will produce more effective techniques to enhance human productivity in space. This will provide the capability to achieve a permanent human presence in space.

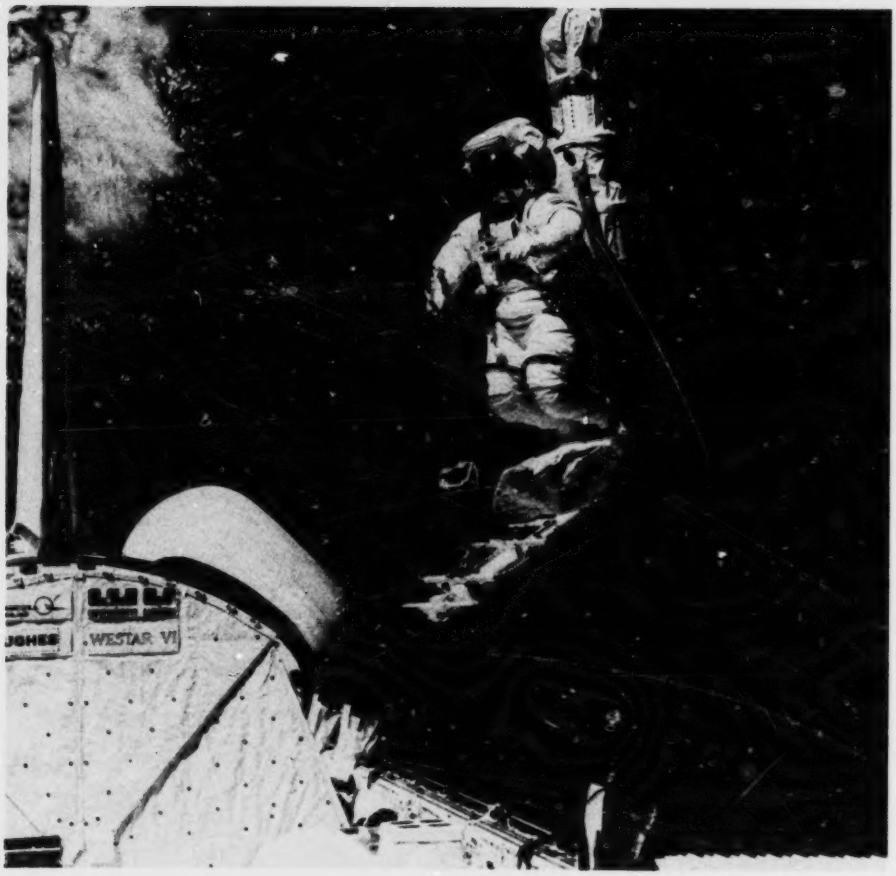

Figure 21.
Astronaut Bruce McCandless II uses the combination of the remote manipulator system arm and mobile foot restraint to experiment with a "cherry picker" concept (February 1984).
NASA

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Biological Research Branch

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The Biological Research Branch explores questions about the fundamental nature of life in the universe that can be answered best by access to space or through capabilities developed from space exploration. The Branch encompasses three interrelated fields of study: exobiology, biospherics research, and gravitational biology. Recently, the CELSS Program was added to the Branch, to recognize the fact that research in the Gravitational Biology and Biospherics Research Programs could contribute directly to developing biologically based regenerative life support systems.

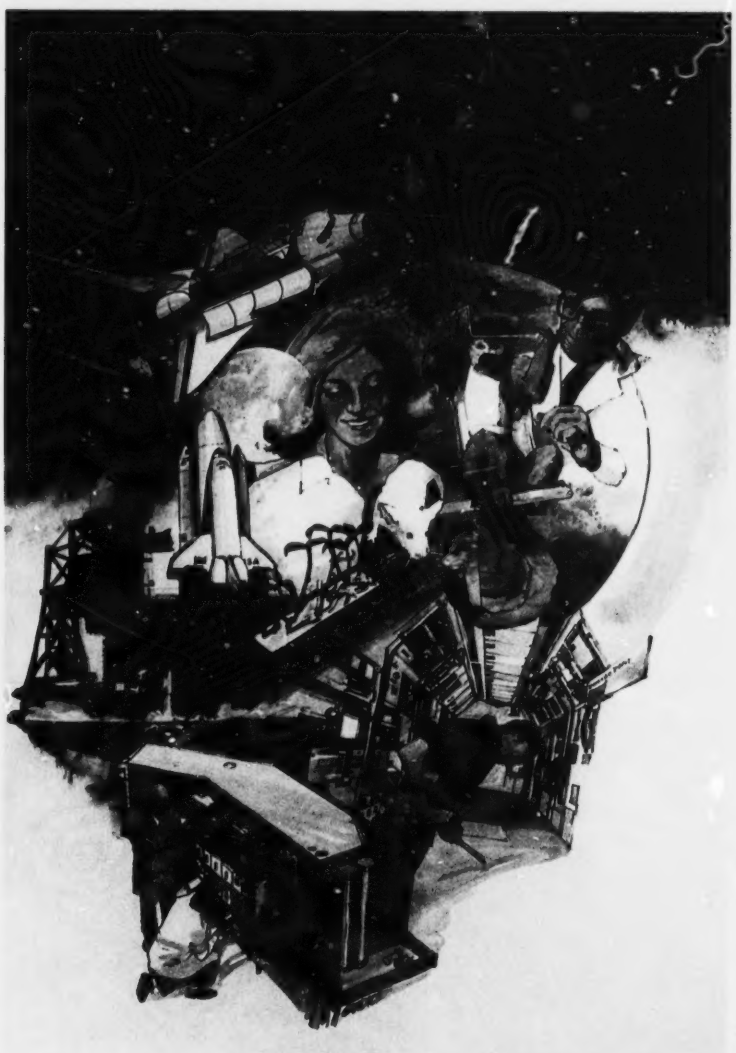

Figure 22. *Space Biological Research*
NASA Artist: Rich Guidice

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Controlled Ecological Life Support System

Up to the present, all NASA manned space missions have been short enough to make it practical to provide life support using expendable supplies of air, water, and food. However, for the 90-day missions of the Space Station, it will be advantageous to use available technology to regenerate the air and water supplies, both to save launch weight and to enable the system to recover from contingencies. Some missions contemplated for the first quarter of the 21st century will be longer than 90 days and will travel to destinations where resupply is either impossible or enormously more expensive than in low-earth orbit. Such missions may include a permanently manned lunar surface base and manned flights to Mars. In these cases it will be desirable and perhaps necessary to regenerate the food supply as well as the air and water within the spacecraft.

A goal of the Controlled Ecological Life Support Systems (CELSS) program is to develop technology needed to make food-regenerating life support systems practical. Most of the energy value in the human diet comes from carbohydrates and fats. The principal waste products produced when these are metabolized are carbon dioxide and water. Therefore, the CELSS program's main technical problem is to develop practical methods for synthesizing fats and carbohydrates from carbon dioxide and water.

Photosynthesis is the only process currently known to accomplish the required carbohydrate synthesis, and many photosynthetic plants also convert part of the carbohydrate they make into fats. Dietary protein can be supplied by plants as well. Thus, the most straightforward approach to regenerating food in a space life support system is to develop ways to grow photosynthetic organisms on a substantial scale in spacecraft and to integrate their life processes with those of the crew, so that all materials essential to both kinds of organisms are recycled continually. The need to engineer this reciprocal interaction is what makes it appropriate to apply the terms "controlled" and "ecological" to the system.

Until recently, the CELSS program concentrated on laboratory research to determine the basic feasibility of systems that could be practical for use in space. Techniques for culturing higher plants and

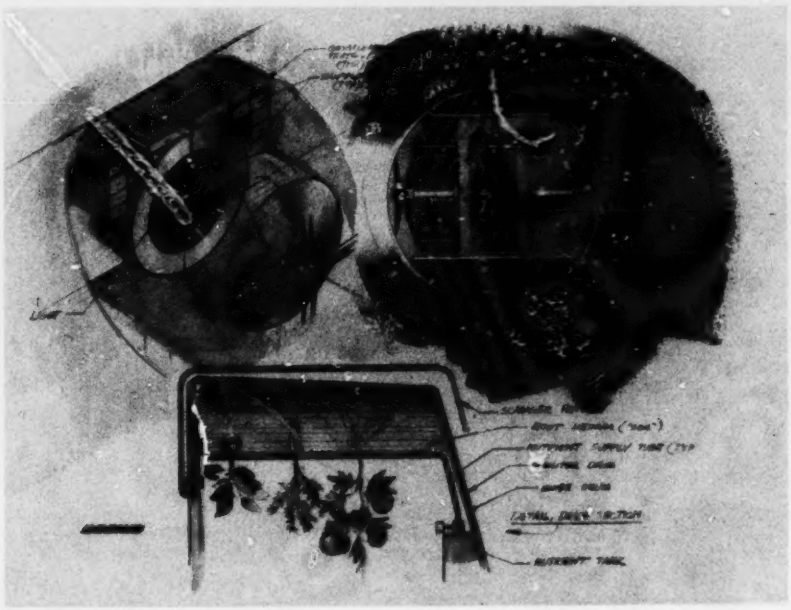

Figure 23A. *CELSS Concepts*
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algae, processes for recycling solid and liquid wastes, and system interactions that could significantly affect performance have been the main topics of this research. In gross terms, the threshold of feasibility for a space system is represented by a power consumption of about 5 to 6 kilowatts and a volume of approximately 20 cubic meters per person.

Laboratory results obtained in 1984-85 show these specifications can probably be met or exceeded. Energy conversion efficiencies (in terms of usable dietary calories divided by the photosynthetically active light energy needed to produce them) in the 7 to 9 percent range have been found for wheat, potatoes, soybeans, and two kinds of algae, whereas an overall system efficiency of 2.5 to 3 percent is needed to achieve the threshold power consumption. Figures obtained on plant and algal productivity in this research indicate that the volume threshold should also be attainable (Figure 23A). The next step toward realizing practical systems must be to scale up the laboratory techniques that produced these promising results. A plant growth chamber with a volume of 60 cubic meters is being set up at the Kennedy Space Center. It will be used to develop large scale plant growth methods that reproduce the CELSS program's research results and to solve operational problems involved in raising diverse crops in a restricted volume (Figure 23B). When satisfactory performance levels are obtained with the plant growth unit, subsystems for water vapor recovery, atmosphere regeneration, food processing (including recovery of human nutrients from otherwise inedible plant parts), and waste processing will be integrated to make a "breadboard" CELSS system. Development of a full-sized engineering prototype will be undertaken in the late 1990's. (With the completion of this project, somewhere near 2001, development of operational hardware for outward-bound missions of the 21st century can begin.) In the next section, many of the problems related to the use of living organisms in a spacecraft containing a CELSS will be presented. Research and insights derived from Gravitational Biology efforts are expected to contribute directly to the production of a bioregenerative life support system for spacecraft.

Figure 23B. *CELSS Concepts*
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Life must accommodate itself to the characteristics of its environment if it is to survive. From this viewpoint, it is unlikely anyone will discover a more constant and pervasive environmental force on earth than gravity. While climate, ecosystems, geologic formations, and living organisms evolve over time, gravity remains stable. As evolution's constant companion, gravity dictated the shape of life, internally and externally, and defined the envelope of our movements and motion. In the struggle for survival of the fittest species, an organism's ability to perceive gravity, interpret correctly the relationship of gravity to its position, and make physical adjustments necessary to prevent damage frequently determines if the organism will survive to maturity. Evolution's survivors, including humans, contain biological mechanisms to sense and use gravity to maintain normal physiological functions (Figure 24).

For humans, the effect of gravity is highly personal. Many pains of childhood — broken bones, cuts and bruises, sprains, concussions — are directly related to incorrectly interpreting the relationship between gravity and movement. As we mature, the relentless pressure of gravity gradually exhibits itself in the symptoms of old age — sagging skin, stooped posture, deposits of fat in the lower torso, edema in the legs, dowager's hump, and other subtler changes that measure our time on earth. Consequently, few questions in biology are as fundamentally important as those related to the interaction of gravity and life.

Figure 24. *The Shapes of Life around Us*
Artist: Jim Lamb (copyright 1983)

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Until the advent of space exploration, there was no way to separate the effects of gravity from other physiological changes that occur over time. Gravity was a constant that could be experimentally increased using centrifuges, but never decreased. Unfortunately, knowing an organism's response to increased gravitation is of limited value in understanding either the intricate and subtle mechanisms that have evolved to allow us to survive in the microgravaity environment of space flight. In experiments with an increased gravitation field (hypergravity), normal gravitational cues are familiar, but the intensity is increased. However, in the microgravity of space, an organism encounters a situation where normal gravitational cues are absent, distorted, or different from those evolution has programmed the organism to expect.

Living organisms that have flown in space can cope with microgravity, making the necessary physiological and behavioral adjustments needed to survive in this new habitat, at least for the short time they have remained there (Figure 25). Identifying and tracing the process of these adjustments gives a truer understanding of the relationship between gravity and life.

The Gravitational Biology Program was formed to merge NASA's resources with biological expertise to gain a better understanding of the relationship between gravity and life. Prior to the Shuttle era, there was little opportunity to conduct gravitational biology investigations in space. Those that were conducted generated results more tantalizing than definitive, raising more questions than they answered, largely because few species flew in space, their sojourn was brief, and there were few resources available for sophisticated experimentation. However, with the Space Shuttle and Spacelab, gravitational biology investigation has entered a renaissance.

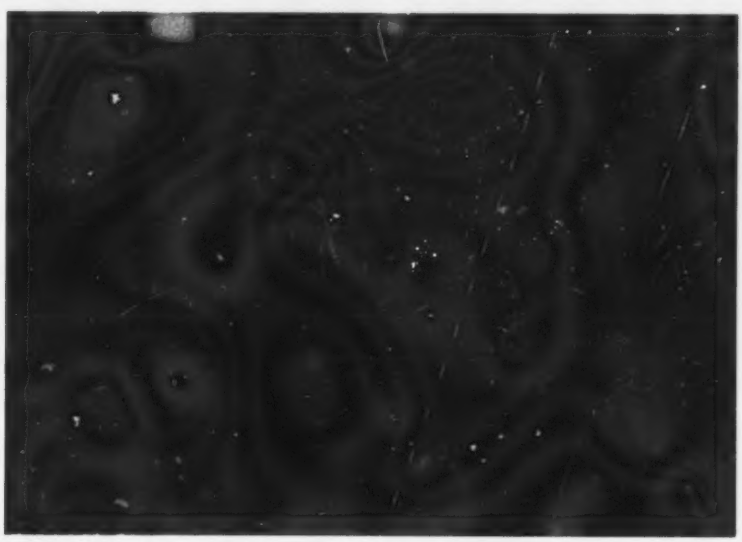

Figure 25. *Space Spiders Build a Web in Microgravity*
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Although flights of the Space Shuttle are relatively brief (compared to the life span of many organisms), they are invaluable since they allow us to answer questions related to a primary companion of evolution — adaptation, the process by which life adjusts to changes in its environment. Consequently, a comprehensive set of objectives, all achievable within the Shuttle and Space Station capabilities, has been formulated. These objectives are defined by the following questions:

How do organisms perceive and transmit gravity information to a site capable of responding to it? What is gravity's role in the life cycle of earth-born organisms? Does gravity's influence extend even into the initial days of life, the development of the embryo or the seed (Figures 26A-26H), and does it affect the maturation and behavior of the organism?

In a cooperative Soviet-American experiment in December 1983, 10 pregnant rats were exposed to microgravity aboard the Biosatellite, *Cosmos 1514*, during the last half of their pregnancy. The rats remained in space for 5 days. Upon return to Earth, the rats completed their pregnancy and delivered pups which were studied to determine whether the mother's flight in space caused any behavioral or anatomical changes. One major difference between pups that developed in space versus pups delivered of earthbound mothers was detected in the vestibular system, a principal gravity sensor in mammals. Vestibular system development and function were retarded in the space pups, indicating that gravitational influence on normal development begins *even before birth*.

Young rats that were grown under conditions of simulated weightlessness showed significant physiological changes. Formation of non-weight-bearing bones was suppressed for about 2 weeks before normal formation resumed. The amount of an important vitamin for bone formation and maintenance, vitamin D, decreased in the blood of these rats for the first week. Even infusing vitamin D into the rats did not significantly change the extent or time course of bone loss. Muscles in these animals were not as efficient or strong as muscles in control animals, causing the remaining muscles to fatigue more readily and to develop increased sensitivity to hormones which regulate muscle mass.

These findings were confirmed and some of the underlying mechanisms for these phenomena were revealed during the flight of *Spacelab 3* early in spring 1985. Twelve adult and twelve juvenile rats were flown for 7 days. On examination after landing, pronounced muscle cell changes were revealed, as were changes in the size and characteristics of certain organs, especially bones. Hormone concentrations varied widely from normal, and production of interferon (an important chemical of the immune system) and growth hormone, essential for a number of physiological processes, was markedly reduced. These findings have implications not only for biological science, but also for the well-being of other mammals in space, notably humans.

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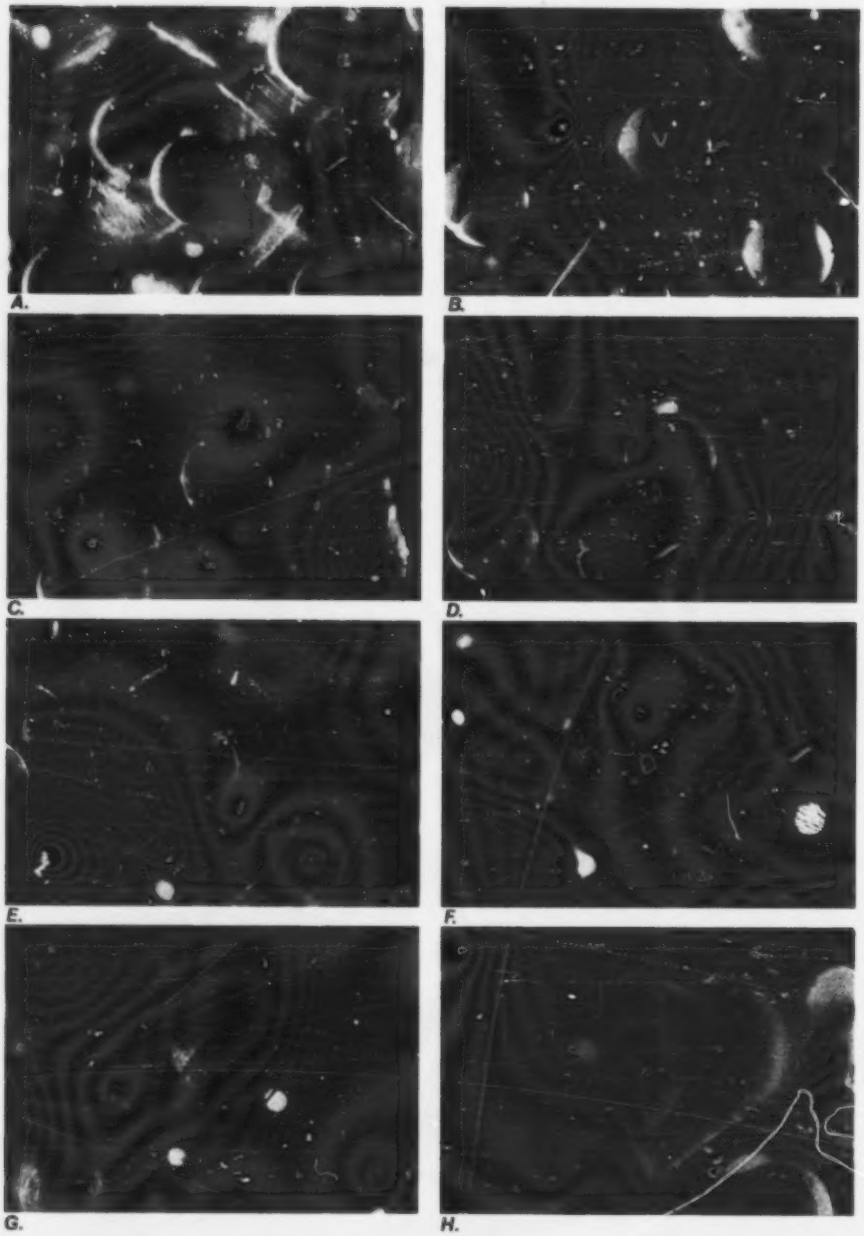

Figure 26A-H. *The developing frog egg - from one cell to many requires precise responses to environmental cues. Carolina Biological Supply*

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Gravity sensitivity has also been demonstrated in plants (Figure 27). When investigators grew plants on a clinostat (a device that simulates weightlessness), they noted profound changes in the life cycle of the plants. Clinostatted plants formed multiple stems instead of single stems, and the appearance of flowers, the growth of seed pods, and the maturation of seeds were delayed. Total seed weight and numbers of pods produced were less than normal. Soviet scientists recently reported a similar maturational delay as well as abnormal seed production in plants grown aboard the Salyut Space Station. Again, this emphasizes the important relationship between gravity and life on Earth and opens new areas of inquiry into the quintessential nature of life.

On another front, scientists investigating gravity phenomena are trying to identify mechanisms that organisms use to perceive gravity and transmit this information to a site capable of processing it. This in turn relates to gravity's control over the form, function, and behavior of organisms.

We have all observed that plant roots orient themselves in a gravity field and grow *downward* in the direction of the gravity vector. Recently, gravitational biologists discovered important clues that clarified further the relationship between plants and gravity.

Over the last three years, evidence was gathered indicating that the distribution of calcium within plant shoots and root tips plays a pivotal role in linking the detection of gravity's directional force with the pattern of cell growth. The movement of calcium within the root changes the pattern of root cell growth until roots are oriented along the gravity vector. Data show the primary cause of altered growth patterns is the gravity-induced asymmetric distribution of a plant hormone called auxin as shown in Figure 28. Gravity stimulation causes calcium and auxin to move toward the lower (down) side of a root's growing zone. The effect of gravity-induced auxin redistribution depends on the calcium gradient in the roots. Auxin is known to retard cell growth in roots. Therefore, the net result of auxin redistribution in roots is that cells on the lower side of roots grow slower than those in the upper portion, making the root grow downward.

Figure 27. *Shuttle Plant Experiment with Principal Investigator Joseph Cowles*
NASA

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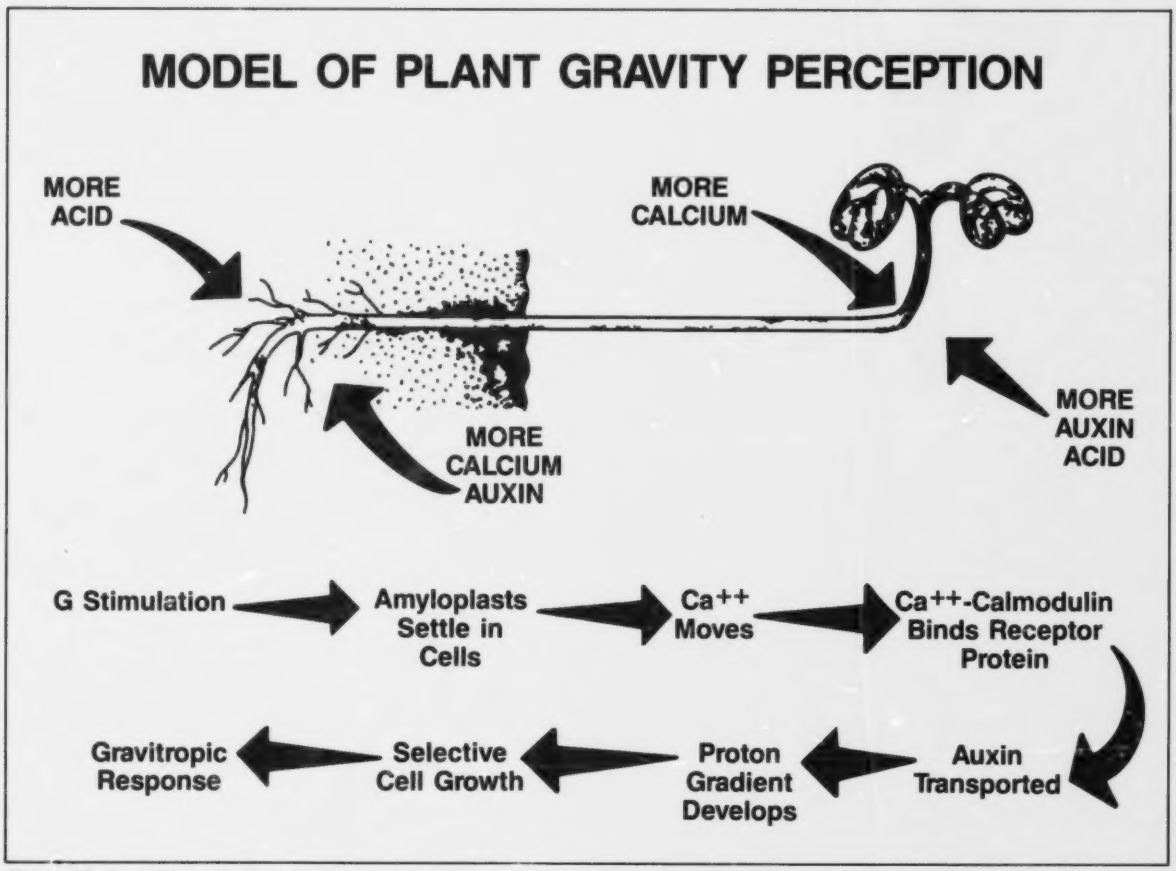

Figure 28. *Plant Gravity Perception*

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If a young plant is placed in a horizontal position, its stem begins to grow upward within minutes. This reorientation occurs because, in the case of stem cells, auxin *stimulates* cell growth and the lower side grows faster. Recent experiments with pea seedlings showed that this response begins simultaneously in all parts of the growing stem and is directed by the same calcium-auxin interaction described previously. This research indicates that the same type of mechanism occurs in stems *and* roots of plants in reacting to gravitational stimulation.

Attempts to localize and identify gravity-sensing devices in plant seedlings have been notably successful. Gravity causes large, dense, organelles, called amyloplasts, in certain plant cells to overcome cyclonic movement of fluids within a cell and settle against the cell wall in the direction of the gravity vector. This settling of the amyloplasts is thought to cause cell membranes to deform, eventually resulting in redistribution of calcium and auxin and subsequent enhanced growth along the lower side of either the root or shoot. It is now widely accepted that amyloplasts are a plant's gravity detector and that the calcium-auxin response affects a plant's orientation in a gravity field.

But what if gravity is absent, as it is in space? Research conducted on Spacelab 1 showed some intriguing behavior by plants in a microgravity environment. Dwarf sunflower seedlings were studied to resolve a question that had challenged plant physiologists for years about the peculiar circular growth movement of plants called nutation. As plants grow on earth, their tips describe a circle around a central axis. Plant physiologists have pondered whether this circular movement depends on gravity or some other environmental stimulus. Results from Spacelab 1 were dramatic: nutation proceeded in microgravity, suggesting the response is programmed into the genetic code of the plant.

When chromosomal studies of root tips were conducted on sunflower and oat seedlings grown on the Space Shuttle, several chromosomal abnormalities were encountered and cell division was significantly depressed. This indicates that the effect of gravity may permeate even into the genetic mechanisms of a cell.

These preliminary investigations are already yielding important results. We have learned about the fundamental behavior of important plant species, and also how to grow and maintain plants in space. However, these studies need to be continued under even lower gravitational fields than so far possible, to determine the threshold of gravity sensitivity. As discussed in the section on Controlled Ecological Life Support Systems, this research contributes directly to developing a regenerative life support system to provide food, water, and a breatheable atmosphere for crews on extended missions.

In the future, specific research will be carried out on Earth and in space to determine the means organisms use to process and utilize gravity information, how microgravity affects the development and function of gravity- sensitive systems, and how gravity has influenced evolutionary progression. Breakthroughs are expected during the Shuttle era that will be used to shape research in gravitational biology aboard the Space Station. The Space Station provides the capability to integrate information gained from discrete Shuttle experiments into a clearer understanding of how an entire organism is influenced by gravity throughout its life and the life of its offspring. Through such tools, scientists will finally be able to explore the complex and fundamentally important relationship between gravity and life on Earth.

When we consider the enormous variety of living organisms in the many habitable environments existing on the planet, the need to maintain global habitability becomes both more imperative and more difficult. In the next section, accomplishments of the Biospherics Research Program are presented together with a glimpse into the problems faced by researchers trying to understand, and ultimately manage, the interaction of life and its environment on a global scale.

Biospherics Research Program

Earth is the anomalous planet in our solar system, the one place where life and liquid water exist. Living and non-living components of the Earth are interrelated in a complex interplay of inextricably linked physical, chemical, and biological processes. These processes are integrated over the entire globe by the land, atmosphere, oceans, and sediments, forming a system called the biosphere (that portion of the planet containing all known life) (Figure 29). It is recognized that biological processes dominate production and removal of many of the biosphere's constituents.

The Biospherics Research Program was formed in 1981 under the name of Global Biology to study dynamics of Earth's biosphere and to understand how living and non-living components of Earth modify each other on a global scale. The program was initiated as part of a NASA interdisciplinary research effort related to global habitability, when public awareness of the fragility of the environment and the significance of large-scale environmental changes was just emerging. Earth-orbiting satellites were generating data that revealed large-scale changes on Earth's surface resulting from volcanoes, fires, flood, and man's continued encroachment on natural habitats. The significance of these changes began to be confirmed by scientists working in remote field sites, where research indicated that a

Figure 29. *The Variety of Life*
NASA Artist: Miriam Schottland

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change in a single location (from increased industrialization, land clearing, or oil spills, for example) had ripple effects on neighboring areas, extending sometimes for hundreds of miles.

One enormous challenge to the Biospherics Research Program is the task of correlating biological, geological, chemical, oceanographic, and meteorological data on a global scale. NASA brought its expertise to this endeavor by conducting planet-wide observational efforts and by processing vast amounts of computer-compatible data. In addition, NASA satellites and specially equipped aircraft provide remote observation capabilities needed to study the characteristics, course, and extent of large-scale biospheric changes.

To determine which laws govern biogeochemical cycling — that is, the constant cycling of living and non-living material throughout the biosphere — the Program is concentrating its efforts in four specific areas: Wetlands, along the eastern part of the United States; Temperate Forests, concentrated at Sequoia National Park; Tropical Forests, represented by studies in the Amazon; and Global Studies, concentrated on biogeochemical models. In the near future, a new effort is planned on Remote Sensing and Public Health, an investigation which will use remote sensing technology to predict the spread of disease-bearing insects. The selected sites are representative of land use change, yet are small enough to permit handling of the data generated in sampling.

Wetlands are the interface between the land and the sea. They are the major natural terrestrial source of many essential trace gases in the atmosphere, such as methane, which is a highly reactive molecule in the Earth's atmosphere. Wetlands are also being changed at a rapid rate, primarily by being drained and converted to agricultural and other uses. For these and other reasons, wetlands provide good laboratories for studying biogeochemical changes. At present, the Wetlands Research Project uses remote sensing instruments tc delineate wetland vegetation types (Figure 30), because the variety of vegetation and the amount present (the biomass) are sensitive indicators of the stability of the region. In addition, the project is

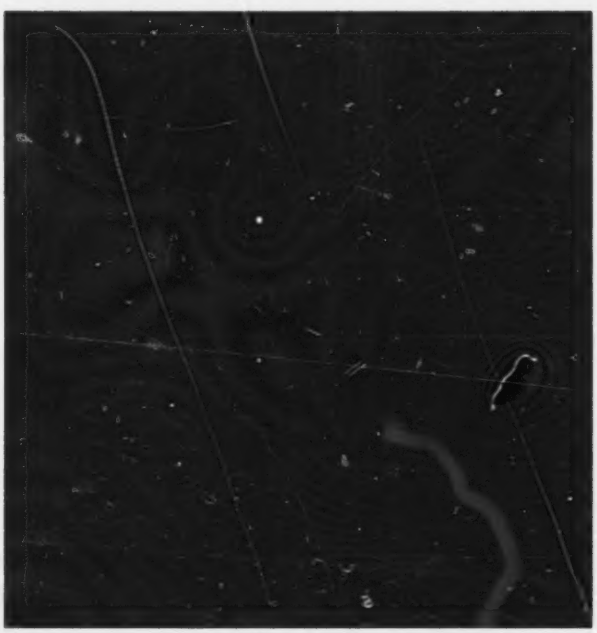

Figure 30. *Methane Flux Map of the Everglades NASA*

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conducting a prototype experiment for estimating methane emissions from wetland ecosystems.

This pilot experiment is being conducted in Everglades National Park and consists of two major tests: evaluating results of various remote sensing devices to determine the utility of each for biogeochemical studies, and developing a computer data base which combines geochemical and geophysical information with measurements of changes in the quantity of methane gas.

Although used as food by some organisms, methane is produced as a waste product by others. Following completion of the first phase of the Everglades experiment, scientists determined that methane gas has been increasing in this region at the rate of 1 percent per year. During the next phase, researchers will use remote sensing technology to correlate this change in methane production with the biogenic sources causing the increase. The first methane flux mapping of the Everglades has been completed. When combined with results from follow-on efforts, this work will help scientists determine "rules" for correlating biologic influences on atmospheric changes. These can be developed into mathematical algorithms, then computerized and applied to other wetland areas until a global picture emerges.

Satellite sensors collect reflected and emitted energy from various sources and convert that energy into signals that can be used to produce different images of Earth's surface. Such images have been used effectively to demonstrate the distribution of different types of vegetation and to infer other details of plant cover. Alteration of the Earth's surface by such phenomena as forest fires or the conversion of forest to farmland results in a net release of carbon dioxide into the atmosphere. Wood harvests can reduce not only the carbon stock of an area, but also the nitrogen stock of forest ecosystems. When nitrogen leaves the forest in harvested material, erosion — accelerated by the harvest — carries off nitrogen-bearing soil. Since carbon and nitrogen are essential chemicals for life processes, they must be available in specific chemical compounds to maintain the health of an ecosystem.

The overall objectives of the Temperate Research Project are to characterize the pathways and measure the rates of biogeochemical cycling of carbon, nitrogen, phosphorus, and sulfur in temperate ecosystems; to model these processes; to identify and map (through remote sensing) key indices of change in the flux of these elements; and to examine consequences of various disturbances in the atmosphere-water-biosphere interaction. Recently, researchers in this Project had the first indication that remote sensing techniques could detect protein content in a forest canopy. Other researchers had already noted a strong correlation between protein content and forest productivity. Therefore, it may now be possible to predict productivity, a measure of the

health of a forest, through remote sensing data.

Of all ecosystems presently under study by the Biospherics Research Program, least is known about tropical ecosystems. Tropical forests are large and important contributors to a balanced ecosystem, but they are currently being disturbed at unprecedented rates by human expansion. Tropical Forest Research Project objectives aim to quantify fluxes of important biogenic gases from tropical ecosystems, and to understand sources, sinks, and processes controlling the flux of nutrients out of the system. In this way, scientists can understand the consequences of human encroachment in tropical forests. This project will measure emissions of nitrous oxide, methane, and other gases in various sites representing major soil types, landscape positions, and disturbances (natural and man-made) as a continuation of the Amazon Ground Emission Project, a collaborative effort with the NASA Earth Science and Applications Division.

The development of mathematical models of regional, continental, and ultimately, global biological processes is one of the greatest challenges facing the Biospherics Research Program. It promises to be one of the most useful tools yet developed for ecosystem management.

Several decades of measurement data reveal seasonal oscillations in the atmospheric concentration of carbon dioxide. Larger variations in amplitude of these oscillations have been detected in the northern than in the southern hemisphere. Since continental land masses are more abundant in the northern hemisphere, seasonal variations of carbon dioxide have been attributed to its release and uptake by land vegetation. In fact, most atmospheric gas concentrations are directly influenced by biology. Composition of the atmosphere and biogeochemical cycling have a major influence on global temperature, climate, and general radiative properties of the planet. Global Studies researchers have developed preliminary formulas to derive the monthly uptake and release of carbon dioxide by terrestrial organisms on a global scale. Global maps (Figure 31A & 31B) show an inverse correlation between vegetation and atmospheric carbon dioxide concentration. Since biology governs production and removal of carbon dioxide and other important chemicals, these models of biogeochemical cycling are crucial to understanding essential aspects of the global system.

The Biospherics Research Program also seeks to apply knowledge gained in its research to the solution of terrestrial problems. In an effort that is just emerging from the conceptual phase, the Remote Sensing and Public Health Project, the goal is to use remote sensing technology to define environmental factors, habitat, vector distribution, and ecology of insect-borne diseases to develop methods for predicting outbreaks of the diseases. Malaria was chosen for this pilot effort because there are tens of millions of new cases of malaria per year.

Malaria is transmitted by mosquitoes. Remote sensing studies of the environment characteristics that drive insect population dynamics can be used to predict the occurrence of malaria outbreaks. The ability to locate disease-fostering environments around the globe may eventually permit identification of prime target areas, so appropriate countermeasures can be instituted to check the spread of the disease.

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Figure 31A & B.
Vegetation Changes Monitored from Space
NASA/GSFC

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Although the Biospherics Research Program is in its infancy, it has the potential to make major contributions to the monitoring and management of Earth resources. In time, scientists may be able to develop global techniques for effective land use management, increased food and fiber yield and biomass productivity, and the repair of ecosystem damage from natural causes and man-made incursions.

While this section explored life's relationship with its planet (Figure 32), the scope of inquiry in the Life Sciences Division includes the quest to understand a living planet's relationship with the universe. The Exobiology Program presented in the next section explores this question and others related to the origin, evolution, and distribution of life in the universe.

Figure 32. *The Earth*
NASA

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Exobiology Program

The Exobiology Program was established to bring NASA resources to bear on questions thinkers have pondered from very early times: Where did life come from? Why is life the way it is? Are we alone in the universe?

While individual researchers and groups of scientists, philosophers, and theologians have debated these questions for centuries, NASA is the only organization in the United States to provide a cohesive, interdisciplinary approach, combining various scientific programs that had conducted investigations since the early 1960s. This integrated approach includes such diverse disciplines as astronomy, biology, chemistry, geology, and engineering. Ground-based laboratory research, astronomical observations, and space missions have been used to seek answers about the origin and uniqueness of life on Earth, the distribution of life in the universe, and the place life occupies in the general cosmology. We are now at the point where scientists can devise experiments to answer these questions.

This new science of exobiology has several objectives. It is searching for an understanding of the origin, evolution, and distribution of life and of the chemicals necessary for life on Earth and throughout the universe. It also strives to clarify the relationship of life to the evolution of planets. Through research in chemistry, geology, and biochemistry, and from planetary exploration, investigators are gathering parts of the origin-of-life puzzle from interplanetary and interstellar space, and naturally, from Earth (Figure 33).

It is now accepted that chemicals contained in living organisms had their origins in the stars. Theories suggest that about 15 billion years ago, there was an incredibly dense, hot region of space that suddenly exploded, releasing great energy, hurling vast amounts of subatomic-sized matter at speeds close to the speed of light into the void. At this moment, our universe — and time as we understand it — began.

Current theories suggest that after the primal nebula was born, virtually all other events became matters of diffusion and independent evolution in the galaxies. As millenia passed, the universe expanded and cooled, allowing matter to accumulate. Then, bound by their own gravitation, these masses became the first stars, born from hydrogen and helium left by the Big Bang.

As some stars ran out of fuel for their nuclear furnaces, they forged new, heavier elements from the "ashes" of hydrogen and helium — including atoms of carbon, oxygen, nitrogen, phosphorus, and sulfur. These are the biogenic elements, or elements of life.

The Exobiology Program's inquiries begin with the creation of biogenic elements, and proceed through the history of these elements as they interact in interstellar space, accrete into planet-sized bodies and solar systems, and finally become incorporated into living systems (Figure 34).

Astronomers, chemists, biologists, and other

Figure 33. *Interstellar Medium*

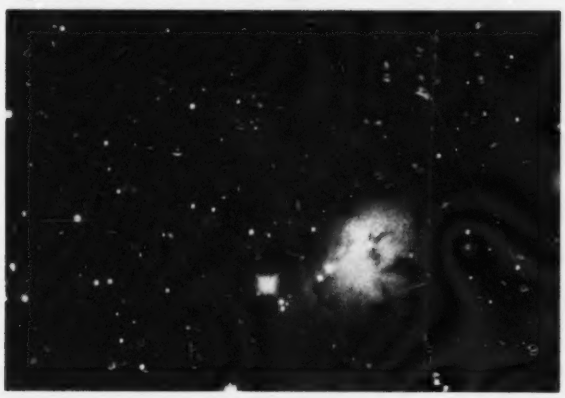
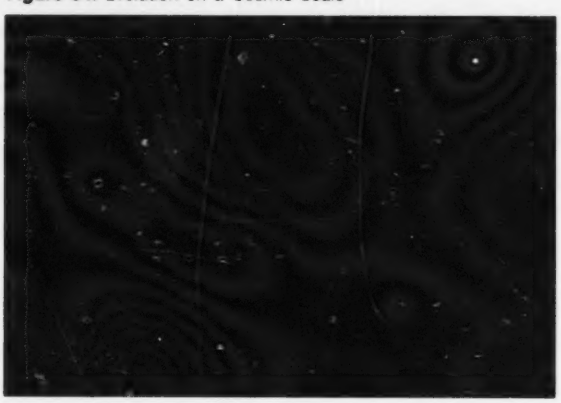


Figure 34. *Evolution on a Cosmic Scale*



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scientists conducting research in exobiology believe that the sequence of events described above may have led to the origin of life on our planet and others as well.

Exobiologists have found evidence supporting this hypothesis through samples and data collected in our own solar system. In the 1960s, scientists began to appreciate the diversity of the planets and to take the first steps toward deciphering their past. Through space programs of the United States and the Soviet Union, the world became a participant in the most dramatic period of exploration and discovery in human history.

During the 1970s, our manned and unmanned explorations revealed an amazing variety of worlds and environments: planets that have no solid surfaces, moons that harbor volcanoes and atmospheres, worlds of ice, oven-hot planets with acid clouds, and one peculiar planet, Earth, with a veneer of liquid water. This diversity exists even though all planets and bodies in our solar system came from a common origin nearly 5 billion years ago (Figure 35). Planets and stars evolve, changing over time, modifying their environments, each following its own course, each dependent in some fashion on changes in its neighbors.

Therefore, the goal of Exobiology is to understand how the origin evolution, and distribution of biogenic chemicals, and their ultimate conversion into living systems, depend on the evolution of the universe itself. How extraterrestrial events, such as solar flares and comets, influence the destiny of life on an evolving planet are also of concern to exobiologists. They want to know what was unique about primordial Earth that allowed life to develop here, if not elsewhere in the solar system. Could life have

Figure 35. *Ring Worlds — Saturn and its Moons*
NASA

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developed beyond the solar system, or is life on Earth truly alone?

One of the first clues to answering these queries came in 1953, when two biochemists built a device simulating earth's environment before the advent of life. When they sparked this environment with an electric discharge (the analog of lightning), biogenic chemicals in the form of amino acids appeared from non-living or inorganic sources. Amino acids are essential ingredients in living systems, the very building blocks of protein. This was the first definitive evidence that components of life could be formed from non-living material resulting solely from the physical and chemical environment. Immediately this raised questions about whether biologically important chemicals and structures can be produced from non-living ingredients on Earth, and whether they can be produced elsewhere in the universe.

The nature of life is such that even the simplest living organism has a structure that defines it, encloses it, makes it an entity distinct from its environment. Within this structure, a complex mixture of chemicals — sugars, amino acids, fats, carbohydrates, proteins, and many other substances— react in an intricate, orderly manner to sustain life. In addition, one of life's key characteristics is its ability to reproduce its kind and conserve its best characteristics throughout generations. Could this highly sophisticated chemical process have come about non-biologically, given the materials present and environmental conditions extant on the primitive Earth?

Answers were forthcoming during the 1960s and the 1970s from a variety of sources. Astronomers using radiotelescopes detected ammonia (a building block of amino acids and other essential biomolecules) and water (the largest single component of living systems) light-years away from Earth in interstellar space. It was determined that comets, among the oldest and best-preserved representatives of the early days of our solar system, contained molecules and chemical fragments of biological significance. Since that time, more important and complex molecules of biological importance have been identified and are still being discovered in extraterrestrial sites. This leads researchers to conclude that organic chemistry is not restricted to Earth, but is in fact a relatively common occurrence in the universe.

During the same period these discoveries were made, amino acids and other biologically significant organic substances were found in meteorites. It has since been determined that these substances were definitely of extraterrestrial origin and that they were formed nonbiologically. Before we went into space, meteorite bombardment seemed an unimportant process. Only about a dozen small meteorite craters were known on Earth, and many thought the Moon's craters were all ancient volcanoes. Scientists now know that intensive bombardment by meteorites in the past was the rule, not the exception, among planets. They found the Moon suffered violent bombardment in its earliest years, more than 4 billion years ago, and conclude that Earth must have been pounded and shaped by similar meteorite impacts.

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In 1983, scientists used non-biological precursors to synthesize an entity that possesses the characteristics of one of the major structural components of living cells — a membrane (Figure 36). This artificial membrane completely surrounds and encloses an interior chemical soup, yet selectively allows passage of certain molecules from the surrounding environment to the interior of the structure, as well as passage of certain materials from within to the outside. This selective ingress and egress of chemicals through a membrane is an essential characteristic of living cells.

Another recent breakthrough concerns the nonbiological synthesis of precursors to genetic materials under conditions that may have been present on the primitive Earth. Genetic materials are the ingredients of reproduction, the "blueprints" of life and conservators of its characteristics. Artificial synthesis of genetic precursors further strengthens the probability that life evolved from chemical processes, and that these types of chemical processes may have occurred at various sites throughout the universe.

In 1984, microfossils were discovered in rocks 3.5 billion years old. This discovery pushed back the estimate of time when life originated on Earth to approximately 4 billion years ago, about the time of an intense meteorite bombardment. Assuming meteorites contain biologically important precursors of life, scientists wonder whether their impacts have actually helped seed the Earth with biochemicals, possibly accelerating the chemical evolution of life.

There are other factors which influence the rate and direction of chemical evolutionary processes. In 1985, researchers found that certain clay minerals showed properties previously thought to be associated only with organic living systems. Their ability to store and release energy, bind and retain biologically important molecules, and catalyze complex organic reactions caused scientists to speculate that clay minerals were important in the origin of life on Earth and may have influenced the rate and direction of chemical evolution significantly.

After life originated on Earth, geological records indicate it proliferated rapidly. Within a relatively short time following its emergence (as geologists reckon time), life had changed the environment of Earth in a manner that favored the continuation and evolution of life. In this sense, life became its own strongest, modulating force.

Recent findings concerning the early evolution of life include discovery of similar genetic material in nearly all living species, again strengthening the argument for a common ancestry. In addition, these studies resulted in the discovery of a microorganism so profoundly distinct from the two kingdoms of microorganisms previously classified, that the international biological community created a third kingdom for its classification. These primitive organisms, the *Archaebacteria*, have altered our concepts of the earliest lines of descent of species on Earth and are providing important clues regarding the route life may have taken while evolving through time.

Figure 36. *Scientist Conducting Research on Cell Components*

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Other research on early evolution conducted in just the past five years has firmly established primary lines of descent of the Earth's earliest life forms. In separate, but related research conducted recently in the Exobiology Program, scientists quantified the magnitude of the effect that life has had on our planet's atmosphere. Evidence gathered suggests that 3 billion years ago, Earth's atmosphere contained 100 times the amount of carbon dioxide currently present. Investigators believe the greatest contributor to this global change was rapidly proliferating, photosynthetic, single-celled life.

There remains little scientific doubt that life, once established on this planet, became a major environmental force. In fact, it appears that the biggest threat to the survival of living organisms is other living organisms.

However, approximately 65 million years ago, long after life was established, the Earth experienced a global upheaval and most of the life on the sphere died in the cataclysm. Scientists now think the cause of this disaster was Earth's collision with a city-sized asteroid or comet. Just last year, exobiologists published a statistical analysis of data that characterized the occurrence of major biological extinction events over the past 250 million years. This analysis supports the startling and highly controversial hypothesis recently presented, that extinctions of whole species and families of organisms occurred periodically throughout Earth's evolution because of collisions with large asteroids or comets (Figure 37).

The search for extraterrestrial life and an understanding of life's origin and evolution continues to draw exobiology into space to find answers. Mars provided exobiology's best opportunity to conduct that search on another planet. With its obvious atmosphere and polar caps, Mars was thought a more likely location to harbor extraterrestrial life. In 1976, the Viking Project landed two robot spacecraft there to photograph surface material and analyze it in detail. Two Viking instruments were designed to search for life and life-related molecules. The results have tantalized exobiologists for the past decade. One instrument showed that Martian soil (at least in the vicinity of the Viking lander) contained no organic materials — not even traces of carbon from meteorites that must surely have hit the planet's surface during its billions of years of existence. The second instrument, sent to discover biological reactions in Martian soil, did not detect life there. It did uncover an intriguing chemical property of soil there that does in part mimic some simple lifelike reactions. Among these are the breakdown of nutrient chemicals and the synthesis of organic matter from gaseous substances. It is thought that this is due to the highly reactive nature of the Martian soil. However, until manned or unmanned explorations revisit this fascinating planet, its greatest mystery, whether there is or was life on Mars, will remain a mystery.

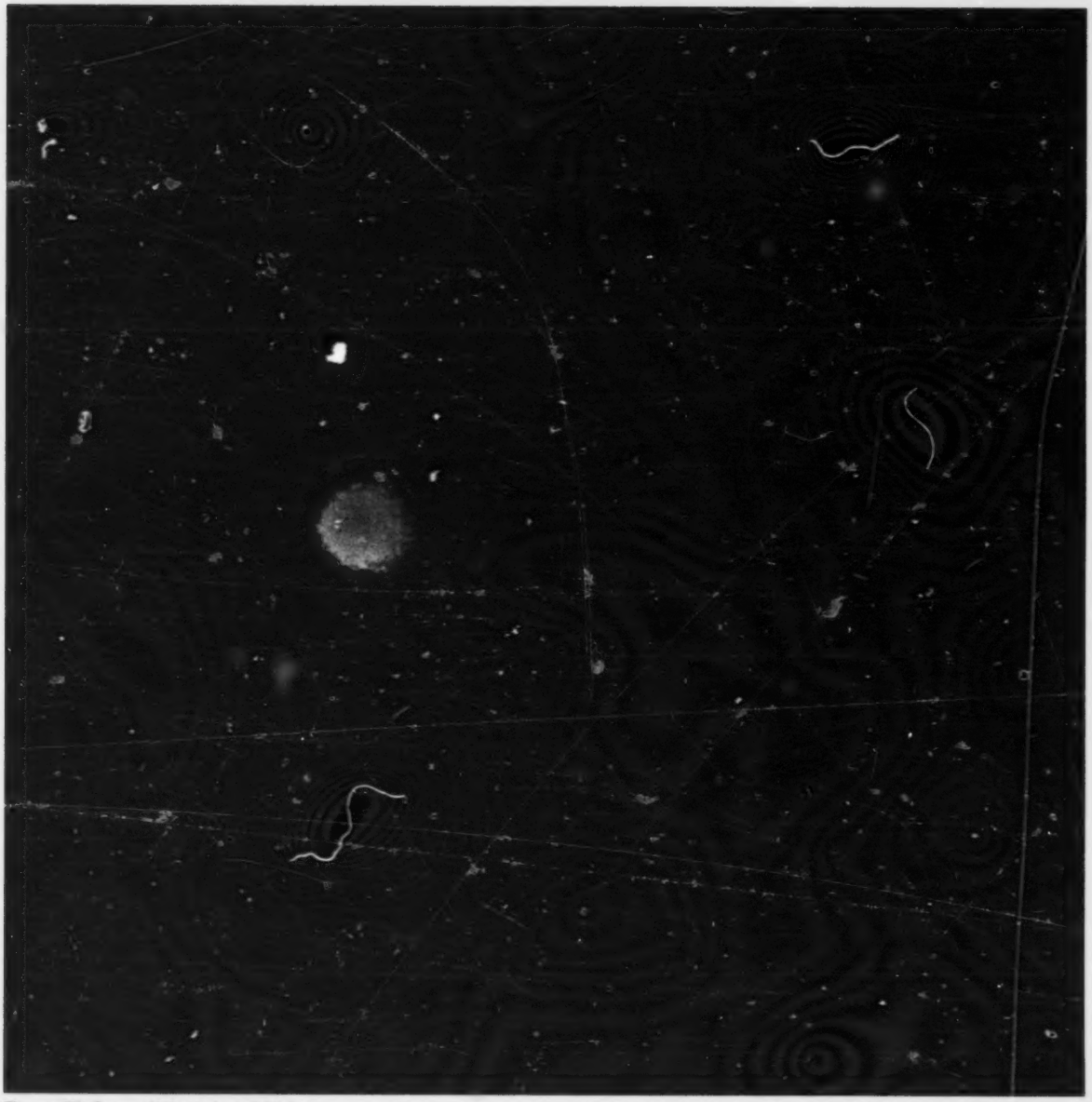

Figure 37. *Comet Kohoutek and Halo*
NASA

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During November, 1980, *Voyager 1* sent data to earth that was to excite the exobiology community. Explorations of *Voyager 1* and *2* spacecraft revealed that Saturn's largest moon, Titan, is covered by a dense atmosphere of nitrogen and methane, with minor amounts of other biogenic elements and molecules. Titan is unique in the solar system. It is a giant world about the size of the planet Mercury, and is the only moon known to have an atmosphere (the most common gas in Titan's atmosphere is nitrogen, just as on the Earth itself). Methane makes up only about one percent of the atmosphere on Titan. More complex biogenic molecules, formed by the action of sunlight on atmospheric gases, might be found in Titan's atmosphere. It is thought that Titan may preserve in its deep freeze a sample of what other primitive atmospheres (including Earth's) were like. This provides exobiologists a planetary laboratory with which to understand early environments before they were modified by phenomena that seem never to have affected Titan: volcanoes, oceans, and life.

Whether extraterrestrial life exists and how life originated and evolved are two intimately related questions. The greater problem is the origin of life. The only life we know in the universe has developed on Earth. Thus, other planets have always been the major focus of our research for other forms of life. If planets are rare, life on Earth may be alone in the universe.

Today, leading theories of star formation imply that planets may be the rule rather than the exception, and that planet formation is expected to accompany the formation of stars.

New discoveries show that chemicals necessary for life are abundant beyond Earth. Therefore, today's research suggests that life could be widespread in the universe. More scientists are now convinced that extraterrestrial life must exist, that contact with other civilizations is no longer something beyond our dreams, but something that will be a natural event in the history of mankind. New information about planets, extraterrestrial chemistry, and the effect of the Earth's environment on the origin and development of life now provide a strong impetus to support the search for intelligent life beyond the solar system. Preparations for the search have already begun.

Scientists from various disciplines joined engineers and computer experts to devise the best, most cost-effective approach to conduct a search for extraterrestrial intelligence (SETI). In the past few months, the SETI test phase was begun at Goldstone Observatory in California, when a special prototype device was installed and tested at the 26-meter radio antenna to listen for radio signals from intelligent extraterrestrial sources.

So begins the future of the Exobiology Program. Work is now underway to conduct Exobiology experiments on NASA's proposed Comet Rendezvous Asteroid Flyby mission. This mission will give the first close-up look at a comet and an opportunity to understand the organic chemistry of the early solar system and its implications for the origin of life on Earth. The Shuttle-launched observation satellites and orbiting observatories are continuing to provide unique information about the formation and distribution of biogenic elements and molecules throughout the universe. Work in this area will continue into the foreseeable future. Preparations are now being made to participate in the next series of Mars missions, the first to be launched within the next few years. These missions may allow us to resolve some of the enigmas presented by Viking (Figure 38). Intense activity is in progress to conduct Exobiology research on Titan as part of the

international Titan-Cassini mission. Further plans include simulation experiments conducted on the Space Station and development of a cosmic dust collector to allow exobiologists to examine particles from interstellar and interplanetary media for biogenic elements and molecules, biological structures, and perhaps even simple living organisms of extraterrestrial origin.

The previous accomplishments in Exobiology and its future plans are all contributors to the overall goal of the program: to understand life's role in the evolution of the cosmos.

Every research program conducted within the NASA Life Sciences Division ultimately requires access to space for its accomplishment. In the next section, work conducted in the Life Sciences Flight Programs Branch is presented to describe the process required for successful flight research.

Figure 38. *Mars, the Enigmatic Planet*

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Flight Programs Branch

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The Flight Programs Branch is the implementation arm of the Life Sciences Division for space research. Thus, it is responsible for providing the flight opportunities, equipment, facilities, and personnel needed to conduct life sciences research in space. In addition, the Branch is responsible for developing a strong community of researchers whose investigations are needed to achieve objectives of the six programs in the Life Sciences Division.

The goal of the Life Sciences Flight Experiments Program is to provide the means to conduct vigorous and ongoing life sciences research in space by developing the research potential offered by NASA spacecraft, beginning with the Space Shuttle and extending through long-duration missions and solar system explorations (Figure 39).

The Space Shuttle and Spacelab are revolutionizing the way research is conducted beyond the Earth's environment. The shirtsleeve environment of the Spacelab and the capability to return results from space-conducted research to Earth for further analysis and development encourages scientists who are not trained astronauts to use the facilities for investigations that cannot be conducted on Earth. Men and women from many scientific and engineering institutions throughout the world are now able to work in space, using familiar procedures and techniques in a fully operational research facility. They are able to handle the equipment, react to unexpected experimental

Figure 39. *Shuttle Launch STS-8 (August 1983)*
NASA

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conditions and results, and transmit data physically and electronically to Earth to gain maximum scientific yield from a mission.

The Spacelab is carried into orbit in the Space Shuttle Space Transportation System (STS), a work vehicle designed to accommodate a variety of payloads and users. The STS consists of both spacecraft and ground-based components. The Space Shuttle Flight System contains the crew, crew compartments, and a 15-by-60-foot cargo bay for payloads (Figure 40). The cargo bay also houses the Spacelab during its flights. In addition, the flight system contains upper stages that allow satellites to be launched from orbit for planetary explorations, communications, scientific investigations, and other special missions. The crew compartments located in the Orbiter middeck provide the capability to conduct small, self-contained experiments and thus allow frequent flight opportunities for research. Part of the STS consists of ground-based integration and launch facilities and ground-based payload operation control centers that support Shuttle missions through pre-launch testing, inflight monitoring, and post-flight servicing. STS can perform many of the services formerly accomplished by unmanned launch vehicles at substantially lower cost, and allows tasks to be performed that had not been previously possible, such as servicing and maintaining payloads in space and retrieving or repairing man-made satellites.

The Spacelab was built by the European Space Agency (ESA), a consortium of eleven countries, through a cooperative venture with NASA. The Spacelab module is a versatile, pressurized facility that contains an enclosed, fully equipped laboratory with utilities, computers, work benches, and instrument racks. The Spacelab can also support experiments attached to outside platforms (pallets) where equipment such as telescopes, antennas, and

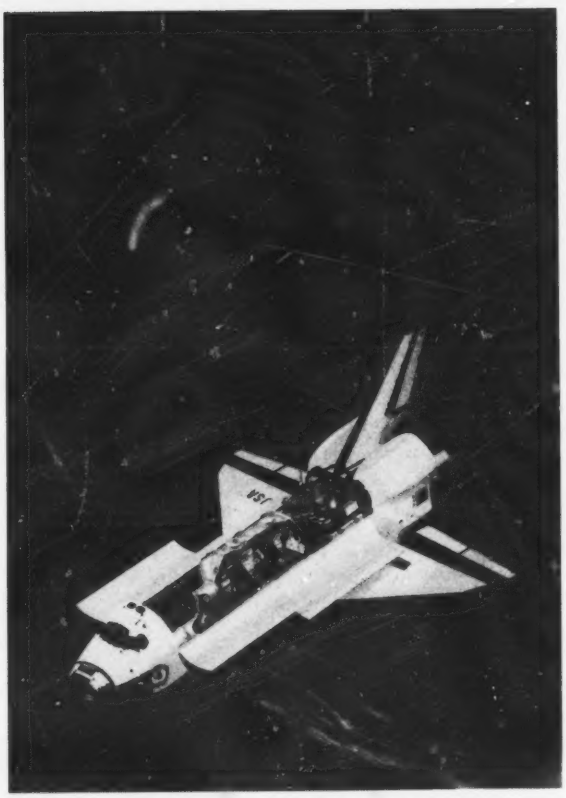

Figure 40. *The Shuttle System: Orbiter, Spacelab, pallets*
NASA Artist: Seijun Fujita

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sensors can be mounted for direct exposure to space. These units may be used in various combinations, returned to Earth, and reused on later flights. The Spacelab can be outfitted with several tons of laboratory equipment that can be reconfigured between missions to meet the demands of a variety of users.

The architecture of the Flight Programs Branch is designed to take maximum advantage of the research opportunities offered by NASA spacecraft. Represented by the Life Sciences Flight Experiments Program, the Branch contains three major elements: flight activities, program development, and administration.

Flight activities, which relate directly to the conduct of space flight investigations, comprise the major portion of the Branch's efforts. Space flight experimentation begins with the receipt of scientific proposals to conduct research in space. Flight proposals are evaluated by all Branches in the Life Sciences Division for their scientific merit, resource requirements, contribution to Division goals and priorities, and feasibility. Each year, certain proposals are selected for implementation, and preparatory research, equipment and procedures development, and flight preparation begins in earnest. Flight scenarios are developed and evaluated, and particular missions are selected to implement the investigations. Once the experiment has been conducted in space, flight activities conclude with analysis and storage of data, and production of a written or published report, which makes results of flight experiments available to the research community at large.

The Life Sciences Flight Experiments Program implements the flight investigations needed to fulfill the broad objectives of the Life Sciences Division (Figure 41). The first is to investigate areas of biomedical research concerned with the safety, comfort, and productivity of humans during space flight. This relates closely to operational flight medicine and insures that all flight problems associated with astronaut health are identified and resolved. Space research provides the data needed to understand the etiology of such problems and deal with them from first principles.

Figure 41. *Life Sciences Payload Specialist Robert Phillips trains for NASA's first dedicated life sciences mission (SLS-1) with Payload Specialists Millie Fulford and Drew Gaffney (right). NASA*

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A second objective is to investigate fundamental questions in biology, especially those related to the effects of gravity on living organisms and the nature of life in the universe. Several routes are available to investigators of gravity phenomena: the use of centrifuges on Earth to impose increased gravitational forces on organisms, the use of certain maneuvers in 1-g that simulate 0-g (bed rest, water immersion, and head-down tilt), and the use of the microgravity environment in space flight to virtually eliminate the presence of gravitational forces. In each case, results of such studies are compared to results of the same studies performed in normal Earth gravity. From these comparisons, specific effects of gravity are discerned.

By inference, it is possible to address an even broader scientific issue regarding the way gravity has shaped life on Earth. This includes consideration of areas such as evolution, organism growth and development, and physiological homeostatic systems (day-to-day challenges to the body by gravity). Questions about these areas of concern can only be ultimately resolved by observing life in an environment devoid of gravity, a requisite condition impossible to achieve adequately on Earth.

Exploring basic questions about the nature of life in the universe requires tracing the history of biogenic elements and compounds from their formation in stars, through their synthesis into planets, to their final incorporation into living systems. Clues to this history are found in space and on Earth. Space flight studies include comparative planetology, cometary studies, simulation experiments, sample collection of interplanetary materials, and astronomical observations of the interstellar environment. As many of these studies involve solar system explorations spanning many years in space, the Shuttle can be used as a testbed for advanced Exobiology experiment equipment slated for planetary and cometary missions. In addition, the Shuttle is useful in field testing experimental concepts prior to their incorporation on Space Station.

Support for life sciences space flight investigations is generated through the Life Sciences Flight Experiments Program. The Program is managed from NASA Headquarters in Washington, DC and is implemented primarily through three NASA field centers: the Johnson Space Center, the Ames Research Center, and the Kennedy Space Center. The centers develop, test, and certify experiments for flight; integrate experiments and other flight items with each other and with the spacecraft, and verify that they are ready for flight. The centers also provide flight experiment-related training for flight and ground-support personnel and support technical and scientific payload-related operations (Figure 42).

Figure 42. *SLS-1 crew trains on LSLE equipment in Spacelab mockup. Payload Specialist Millie Fulford (left) checks a LSLE device used to examine pulmonary function in space. Astronaut Jim Bagian tests the LSLE Body Mass Measurement Device (center) and Payload Specialist Drew Gaffney (right) wears the LSLE neck chamber system to evaluate cardiovascular performance. Bicycle ergometer (foreground) is LSLE equipment that will also be used in cardiovascular studies.*

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Further, the centers provide the data processing necessary to support preflight, inflight and postflight experiment requirements. The principal investigators associated with life sciences space flight investigations come from a variety of locales — universities, government and NASA centers, industry, and other research institutions.

During the first half of this decade, the Flight Programs Branch concentrated on developing experiment opportunities using the Space Shuttle to carry out life sciences investigations, outfitting space life sciences laboratories, and developing the investigator community needed to achieve maximum science return from life sciences investigations in space (Figure 43A-K).

By the end of 1984, the Branch had developed capability to support various classes of experiments on the Space Shuttle: small self-contained experiments, minilab experiments, and experiments requiring resources provided by dedicated Spacelab missions. This capability provides the greatest flexibility for conducting life sciences research in space during the Shuttle era, because it permits Life Sciences Division to take advantage of a number of different types of flight opportunities.

The most important flight resource available to the Life Sciences Division is the sophisticated laboratory facility available on Spacelab missions. Spacelabs can be dedicated entirely to life sciences research. NASA's first dedicated life sciences mission, called *Spacelab Life Sciences 1* (SLS-1), is being designed to gather data on biomedical and biological processes never before collected in space. Dedicated missions are advantageous because the entire payload crew will have special expertise in life sciences. Therefore, more complex experiments can be conducted. In addition, planning a dedicated mission assures that the experiments will be tightly integrated, both scientifically and operationally. On SLS-1, parallel experiments in humans and animals will be conducted to allow a correlation and additional insight into the relationship between space flight effects on animals versus humans. If this correlation is significant, more intensive studies can be made on animals in future flights. This will markedly advance our ability to understand and treat human space flight problems. Over the next decade, the Division plans to conduct five dedicated life sciences missions as preparation for the Space Station.

Because of its versatility, a number of Spacelab missions are shared by several disciplines, such as astronomy, materials sciences, or earth sciences. In addition, most Spacelab missions are shared by U.S. and foreign scientists. *Spacelab 1* (SL-1), launched in November 1983, contained experiments contributed by Britain, Germany, Switzerland, Italy, France and the United States. The first IML (International Microgravity Laboratory) mission, scheduled for launch in 1987, will contain Canadian, European, French, and American investigations in both Life Sciences and Materials Sciences subdisciplines. A total of five IML missions are planned over the next decade. From these joint missions, international working groups of scientists have begun establishing a solid basis for sharing ideas, results, and experiences.

Figure 43A-K. *Insignias from Shuttle Flights carrying Key Life Sciences Experiments.*
NASA

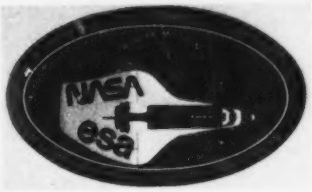
A. STS-4

B. STS-5

C. STS-6

D. STS-7

E. STS-8



F. SL-1

G. STS-11

H. Mission 41-D

I. Mission 41-G

J. Mission 51-E

K. Mission 51-B, SL-3

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Prior to conducting a full experiment in space, it is often desirable to test a piece of related equipment to assure its proper functioning during space flight (Figure 44). A novel concept for a potentially important research study may need to be validated in space to test the idea before a full research effort is implemented. In these cases, it is useful to have available a fast-turnaround mode for performing these tests. This capability is provided by a type of flight study called a Detailed Test Objective (DTO). Because they are only tests, DTOs do not have the priority given peer-reviewed, selected, and approved flight experiments, nor is there the commitment to the rigorous engineering design and checkout tests afforded a regular study. A relatively high risk of failure is accepted for DTO's, because their purpose is to conduct quick "proof-of-concept" tests of ideas.

To take advantage of resources that may be available on the Shuttle late in preparation for flight, the Flight Programs Branch has instituted the Small Payloads Program. The middeck of the Shuttle Orbiter contains sufficient stowage and work space to perform a variety of scientific studies. In addition, there is frequently a small amount of space available in the Shuttle cargo or payload bay not being used to meet primary mission objectives. These capabilities make available many more flight opportunities for research, since Spacelab flights are relatively infrequent. Compared to Spacelab missions, the capabilities of the middeck and payload bay are limited with respect to power, experiment facilities, equipment size, and crew time. However, a number of life sciences experiments are self-contained and require minimal crew interaction and external power; therefore, they can be conducted either in middeck lockers or on carriers in the Orbiter payload bay. This concept allows NASA to gain the maximum science return from a mission by utilizing all available resources in the spacecraft.

A number of flight experiments have already been conducted in the Orbiter middeck. Data collected on these studies have been extremely useful in such diverse areas as cell biology, plant growth, radiation, and medical science, including hallmark experiments in motion sickness, vestibular function, and cardiovascular function.

To support experiments in the Shuttle and Spacelab, the Flight Programs Branch has developed the most complete inventory of flight-qualified laboratory equipment for life sciences

Figure 44. *SLS-1 Astronaut Jim Bagian uses LSLE equipment to evaluate pulmonary function.*
NASA

space flight research ever assembled. This equipment facilitates flight research on a variety of organisms including cells, tissues, plants, animals, and humans. The Life Sciences Laboratory Equipment (LSLE) are used whenever possible to reduce new equipment development and program costs. As required, new items are developed and added to LSLE to meet special requirements of particular investigations (Figure 45). Over 70 LSLE items are currently available to space researchers. These items include controlled habitats for plant, animal, and microbiological investigations, plus sophisticated physiological monitoring and measurement devices needed to study responses of these organisms in space. Of particular note is an array of LSLE medical laboratory equipment which permits the study of humans in space.

The Life Sciences Division, cooperating with the Flight Programs Branch, has developed three mechanisms by which life sciences researchers have access to space flight resources for further research. The prime mechanism is the "Announcement of Opportunity OSSA-2-84," a formal solicitation for life sciences investigations in space. Approximately 100 scientists from research institutions throughout the United States and abroad responded to this AO in 1984. Two more AO selections are planned for the last half of this decade. Investigations selected from these proposals will form the nucleus of life sciences research in space for the rest of this decade and will lay the foundation for Space Station research. The purpose of the AO is to solicit investigations in all life sciences disciplines for conduct primarily aboard the Spacelab and, later, aboard the Space Station.

Another important mechanism for obtaining life sciences space flight investigations and for maximizing flight resources is the Dear Colleague Letter issued by the Gravitational Biology Program entitled "Emerging Opportunities in Space Biology." This letter invites scientists to submit investigations for gravitational biology research that can be conducted in the middeck area of the Shuttle Orbiter. In addition, the Space Medicine Branch has also developed a Dear Colleague Letter for investigations of medical problems unique to space flight and its release is imminent.

A third mechanism, the Flight Sample Bank, is designed to yield greatest scientific return from a given mission and broaden involvement of the life sciences community in space flight research. Flight specimen samples not required to support principal experiment requirements are made available through the Bank to life sciences researchers for analysis and study. The success and utility of the Sample Bank concept was demonstrated during *Spacelab-3* when an animal holding facility verification test was performed. Postflight sample bank studies were performed on 24 flight rats. Results of these investigations helped validate hypotheses and also generated some startling insights in areas of bone demineralization, muscle atrophy, and general metabolic alterations. For instance, early analysis of rat tissue samples indicated that anti-gravity muscles in the leg and neck may have lost up to 50 percent of their mass, and weight-bearing bones appeared to have lost about 10 to 12 percent of their mass during this 10-day mission. Implications of these results to long-term space flight are presently being evaluated by scientists in the Space Medicine and Gravitational Biology Programs.

The Flight Programs Branch recently opened negotiations with the international community to explore areas of mutual interest in space life sciences research. These efforts revolve around sharing resources to enhance hardware/equipment development and flight opportunities. International cooperative investigations during 1984 and 1985 included Hungarian radiation dosimetry middeck experiments, Canadian space adaptation syndrome experiments, and French vestibular and cardiovascular experiments.

In preparing for the future, the Flight Programs Branch shares the Life Sciences Division's commitment to develop the talents of our nation's young people through the unique resources and excitement offered by space flight. In 1984, the Life Sciences Division led an OSSA effort in collaboration with NASA's Office of Equal Opportunity to conduct

a six-week, space life sciences training program for college students (Figure 46). This program is a "hands-on" experience for students, permitting them to observe and participate in developing, flying, and analyzing results of life sciences experiments conducted in space. In the Shuttle Student Involvement Program, the Flight Programs Branch supports a NASA and National Science Foundation joint program for high school students by working with the students to implement their experiments in a variety of biological and biomedical areas, including honeybee hive construction in microgravity conditions and the effects of weightlessness on the development of arthritis in rats. It is hoped these students will be stimulated to consider space flight research when defining their professional science goals, and that they will become aware of invaluable resources offered by space flight to resolve biological and biomedical questions.

The Life Sciences Division has already conducted a number of investigations in space during the Shuttle era. These are presented in summary form in Appendix 1. The Flight Programs Branch will support future Division efforts to establish and maintain a permanent human presence in space aboard the Space Station, and to use its facilities to expand knowledge in the biological and biomedical sciences. In addition, the Flight Programs Branch will support a series of unique space observatories and solar system exploratory missions that can contribute directly to answering fundamental questions in Exobiology. In this way, all elements of the Life Sciences Division work together to make space an extension of life on Earth (Figure 47A).

Figure 45. *LSLE General Purpose Workstation — A space-qualified containment facility needed to perform laboratory functions in microgravity NASA*

Figure 46. *Hands-on experience in flight preparation by students in the Space Life Sciences Training Program. Preparing for Spacelab 2 mission. NASA*

Figure 47A. *New Horizons NASA Artist: Robert T. McCall*

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There are jobs to do in space. The Space Shuttle, more than any other vehicle in space flight history, has established that fact beyond question. Every day, scientists, industrial representatives, and inventors contact NASA to relate their ideas for unique space flight studies that will significantly advance our understanding of the universe or generate products needed on Earth but only able to be manufactured in space. Most of these creative people politely voice a common complaint — they need more time on orbit than the Shuttle provides to develop their ideas fully. They need a Space Station.

In 1983, by Presidential directive, NASA initiated an accelerated effort to plan, design, build, and launch a Space Station by 1995 to maintain "a permanent human presence in space". The challenge to NASA included the following elements. The Space Station must provide laboratory facilities for space flight research in a variety of disciplines, including life sciences, materials processing, industrial research, planetary studies, and astronomy. It must provide the capability to retrieve and repair satellites and research equipment on orbit. It must provide the capability for men and women, professional astronauts and non-astronaut professionals, to live and work safely for extended periods under conditions that promote optimum productivity. There must be the capability for research scientists on Earth to interact directly with their colleagues or with their experiments aboard the Space Station. There must be a way to return the products of Space Station efforts to Earth on a routine basis. And, finally, there must be the capability to use the Space Station as a vehicle processing and launch site for future explorations of the universe.

The best scientific, engineering, and administrative talent was assembled to determine how this might be accomplished within the budget constraints imposed. From these deliberations, Life Sciences was given the responsibility to fulfill its two broad goals within the context of the Space Station environment: assure the health, well-being, comfort, and productivity of Space Station and Shuttle crews (Figure 47B); and take maximum advantage of resources provided by the Space Station to further our understanding of the nature of life in the universe.

The Life Sciences Division began immediately to define the scope of medical problems likely to be encountered during Space Station activities by drawing on its experience from the Skylab missions, and adding to that, knowledge being generated from Shuttle experiments. The first general problem involved is defining habitability requirements for the Space Station. In this area, problems such as delivering a balanced, nutritional, and interesting diet became more acute, especially since diet in the Space Station environment serves three main functions: it naturally provides basic nutrients, and it can serve as a therapeutic agent for minimizing physiological changes that occur in space as well as

Figure 47B. *Preparing for the Future. Payload Specialist and U.S. Senator E. J. (Jake) Garn conducts a medical experiment on himself in a typical 51-D Garn scene, as the senator was scheduled as a test subject for extensive medical tests onboard. This particular experiment deals with gastric motility. Principal Investigator for this experiment is Astronaut William E. Thornton, a physician.*
NASA

provide a psychological reward and sense of well-being. The control of microorganisms and toxic substances in the Space Station becomes more difficult and more imperative because the Space Station (Figure 48) habitability module will not be returned to Earth for cleaning and maintenance on a regular basis.

The second problem occurs because Space Station crews will conduct frequent EVAs involving increasingly more complicated maneuvers (Figure 49). There will be combined systems that employ both human and automated functions. Design requirements for these systems must be developed to ensure optimum productivity. Consequently, the current EVA suit must be redesigned to increase its flexibility and ruggedness. Further, special EVA protocols must be developed to reduce pre-EVA preparation requirements to minimize their impact on crew operations.

Third, routine and emergency space medical care procedures must be developed so Space Station crews can handle situations that are likely to occur. Medical care in the Space Station revolves around the following conditions. In its initial phases, at least, the Space Station will not have an emergency return-to-Earth capability; therefore, onboard diagnostic, clinical treatment, and even emergency surgery facilities will be required to handle a variety of normal and industrial-type accidents. Problems related to long-duration exposure of humans to the space environment will become evident: especially bone demineralization, muscle atrophy, and accumulated radiation exposure. Hence, countermeasures to these problems are needed. Finally, issues concerning long-term habitation in a remote site need to be addressed, such as group dynamics, control of toxic materials, and environmental design.

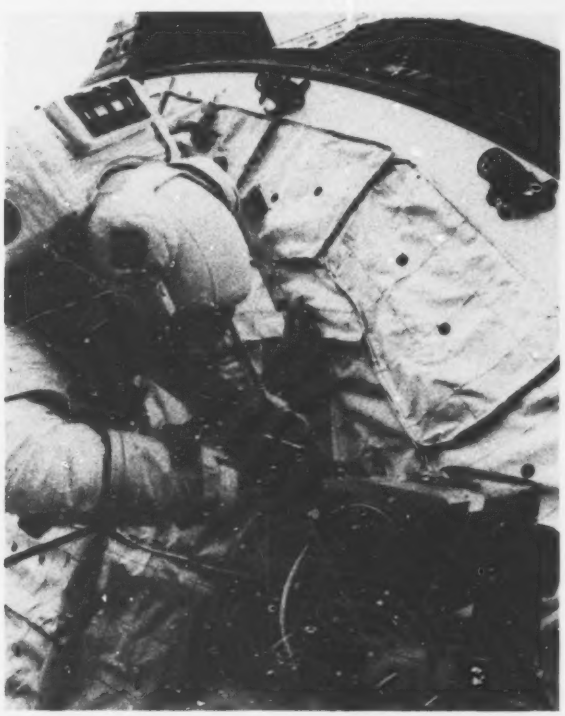

Figure 49.
Clean Outdoor Work
NASA

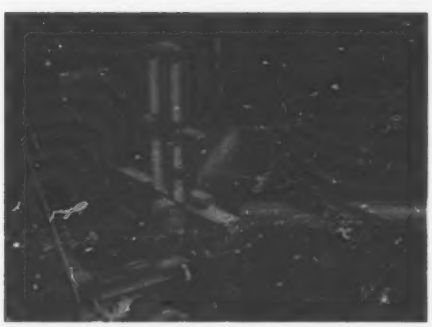

Figure 48.
Space Station Concept

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These issues are all being considered. Our experience on Skylab and that of our colleagues in the Soviet Salyut give confidence that humans can live safely and well in space for the 90-day periods initially planned for Space Station — provided proper precautions are taken. However, as we look beyond Space Station to future missions, it becomes apparent that humans will be required to spend increasing periods of time in space to prepare for planetary missions and solar system explorations. The insights needed to assure these goals in safety will result from an amalgamation of research conducted within all Branches and programs of the Life Sciences Division.

In their pursuit of knowledge and understanding, the Division's basic research efforts provide valuable information that can be used to help resolve medical issues. The Space Station offers gravitational biologists their first opportunity to study the influence of gravity throughout the life cycles of living organisms: from birth through maturity, from reproduction through aging and death. Using these studies we will also learn how humans who spend months or years in space will be affected by the microgravity environment, so that better countermeasures can be developed.

Exobiology researchers will use the Space Station for a variety of purposes, as it offers an unobstructed view of the heavens, platform facilities for sample collection of interstellar and interplanetary particles, and laboratory capabilities for sample analysis and modeling studies of planetary and interstellar environments. In addition, the Space Station will eventually offer launch facilities for solar system explorations and planetary sample returns. Through these studies, exobiologists will provide significant advances in our understanding of life's relationship with the universe. They will also help characterize the types of environments humans will encounter during their explorations of the planets.

By synthesizing concepts inherent in gravitational biology and biospherics research with sound engineering principles,the CELSS program will produce a regenerative life support system that will be tested first in Space Station. By doing this, CELSS will begin to lower the cost of Space Station operations by reducing the need to resupply materials from Earth, and provide a life support backup in event of contingencies. CELSS will be part of future spacecraft designs that will carry people to other worlds and will be built into planetary and lunar bases (Figure 50).

Achievement of these goals will rely heavily on the expertise developed within the Flight Programs Branch to translate ground-based laboratory designs into flight-worthy projects.

Therefore, contributions from all programs within the Life Sciences Division are needed to make Space Station a viable enterprise. Concepts discussed in this report are only a few of the challenges and opportunities to be considered in preparation for our next phase in space. In subsequent reports, we will present more detailed plans, descriptions, and achievements and describe further benefits to be derived from our nation's explorations in space.

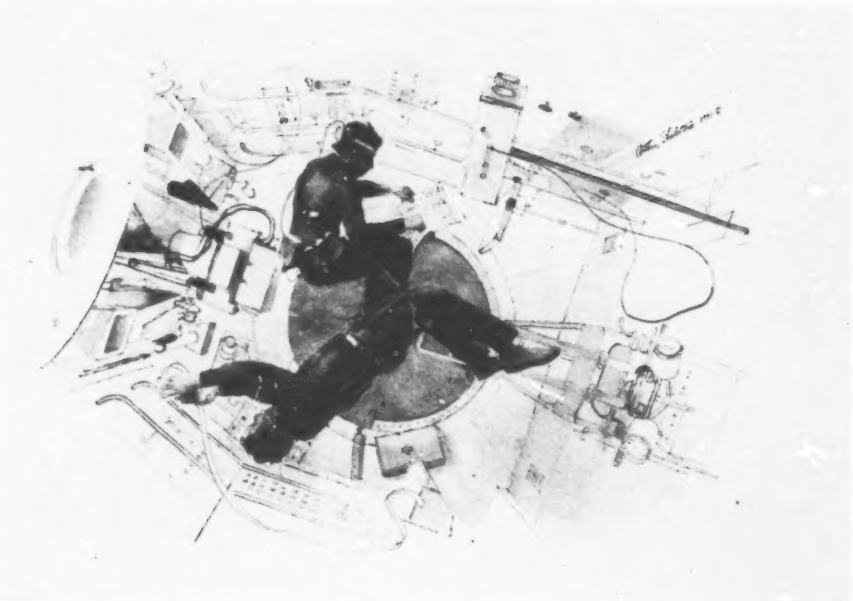

Figure 50. *Living and Working Space NASA Artist: Arthur Shilstone*

APPENDIX 1
Significant Milestone Events

1975

The Life Sciences Division was formed to bring biological and biomedical research conducted throughout NASA under one roof. The original Life Sciences Division consisted of four programs: Biological Sciences, Medical Sciences, Biomedical Systems and Operations, and Life Sciences Payloads and Applications.

Life Sciences Division released "An Invitation to participate in planning the NASA Life Sciences Program in Space" that solicited input for Shuttle-conducted research from scientists both within NASA and from outside universities and research institutions. In this way, the life sciences community played a dynamic role in the identification and early development of the life sciences space flight program objectives and implementation.

During July 1975, the first international space mission was conducted — the Apollo-Soyuz Test Project. U.S.-U.S.S.R. joint space flight experiments included the transfer of cosmonauts and astronauts from their respective spacecrafts. Four U.S. Life Sciences experiments were flown on the Soviet *Cosmos 782* flight in November 1975.

New species of algae, bacteria, and fungi were discovered living inside rocks from the coldest, driest deserts of the Antarctic, which represent the closest terrestrial analog to the environment of Mars.

1976

Viking 1 landed on Mars July 20, 1976. *Viking 2* landed on Mars September 3, 1976. Viking experiments in exobiology found no existing life or organic chemicals in the soil at two locations on Mars. However, Martian soil was found to possess intriguing chemical properties that mimic, in some respects, certain reactions of biological systems.

Life Sciences formulated plans to conduct research on the Space Shuttle using dedicated Spacelab missions, minilabs in Spacelab, and carry on experiments in the Shuttle Orbiter middeck area.

Two Announcements of Opportunity were released for the first and second Spacelab missions, *Spacelab 1* and *Spacelab 2*.

Figure 51. *Life Sciences Division Emblem NASA*

1977

Life Sciences experiments were selected for implementation on *Spacelabs 1* and *2*.

1978

Life Sciences released Announcement of Opportunity AO-1-78, formally soliciting investigations for NASA's first dedicated life sciences mission — *Spacelab Life Sciences 1*.

1979

Over 350 proposals were received in response to AO-1-78. Evaluations were initiated to determine scientific merit, contribution to Division goals, and engineering, management, and cost requirements of these proposals.

In the Exobiology Program, a third kingdom of microorganisms, the *Archaebacteria*, was shown to be distinct from the prokaryotes and eukaryotes, thus altering concepts about the earliest lines of descent of species on Earth.

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1980

Voyager 1 encountered the Saturn system, and revealed features of Exobiology interest on Saturn's largest moon, Titan.

Implementation plans were completed for medical operations in support of Space Shuttle missions.

Life Sciences experiments were selected for *Spacelab 3*, where primary life sciences objectives included equipment verification test on Research Animal Holding Facilities and the Urine Monitoring System.

1981

Voyager 2 encountered Saturn at a distance of less than 100,000 miles. Plans were initiated in Exobiology to develop an experiment package to be carried on the Titan mission.

Twenty-five investigations on cells, plants, animals, amphibians and humans were tentatively selected from AO-1-78 proposals to comprise the payload of *Spacelab Life Sciences 1*. Mission preparation and flight equipment engineering began in earnest for this mission.

NASA selected six U.S. Life Sciences proposals for consideration on U.S.S.R. Cosmos '81 mission.

A conference was held on Global Terrestrial Ecology: "Interaction of the Biota with Atmosphere and Sediments." Fifty leading national and international scientists participated in this conference which led to the development of the Biospherics Research Program (formerly called Global Biology).

The Operational Medicine Program developed and updated standards for astronaut medical selection and retention (annual) medical certification standards; pre- and postflight medical examinations of STS crews; early detection, prevention and/or treatment techniques for handling crew illnesses; biomedical training of space crews in emergency medical procedures; and training of NASA/DOD medical personnel in principles and practice of space medicine.

The Operational Medicine Program initiated acquisition of trend data to elucidate the time course of long-term effects from repeated exposure to space flight; developed health-maintenance protocols (such as exercise, anti-cardiovascular deconditioning measures, space motion sickness predictors and/or drugs), procedures, equipment, and environmental monitoring for use during space missions; and developed simulations of STS flights that facilitate the testing and development of specific medical protocols on the ground prior to their use in space.

Clay minerals that markedly influence the rate and direction of chemical evolution processes were found by Exobiology researchers.

Maiden voyage of the Space Shuttle occurred April 12, 1981 with the flight of *Columbia*. The mission lasted 54 hours and 21 minutes. Crewmembers experienced symptoms of cardiovascular deconditioning during re-entry.

1982

The Biospherics Research Program was formulated in the Life Sciences Division under the name of Global Biology.

The Division initiated a task in Data Analysis to derive the maximum possible benefits from life sciences space flight data.

The Division initiated the Advanced Technology Development efforts to conduct state-of-the-art engineering research on equipment that will have important space flight and ground-based applications. One of these efforts was focused on developing a regenerative life support system (CELSS).

Operational Medicine and Biomedical Research were combined into one program called Space Medicine. Efforts began to develop the technology needed to improve Shuttle atmospheric carbon dioxide removal, eliminate EVA prebreathing, provide EVA systems for satellite servicing, and improve water management for STS missions. Increased emphasis was placed on the development and testing of countermeasures.

STS-3 mission occurred March 22, 1982 for 8 days and represented expanded manned tests of the STS vehicle. This flight included the HEFLEX Bioengineering Test on a special plant growth unit to support space biology plant physiology experiments in the Shuttle Orbiter middeck and an experiment on plant lignification.

STS-4 mission occurred June 27, 1982 for 8 days and represented the first operational flight of the Space Shuttle. Validation of predictive tests for space motion sickness was conducted and a cardiovascular deconditioning countermeasure was verified.

STS-5 launched November 10, 1982 and remained in space for 5 days. This was the first launch of a four-member crew and was the first entirely manual reentry and landing. Tests of neurovestibular function and acceleration-deceleration sensitivity were conducted.

1983

CELSS was initiated under the Biological Research Branch as an ongoing program.

Gravitational Biology Program released a Dear Colleague Letter to encourage proposals in space biology for research to be conducted on the Orbiter middeck.

Gravitational biologists developed an integrated hypothesis of the physiological mechanisms by which plants detect and use gravity information.

Space Biomedical Research Institute was established as a vehicle for solving the most pressing biomedical problem in the early Shuttle era, space motion sickness.

Microfossils were discovered in rocks 3.5 billion years old by Exobiology researchers. This finding pushed back the estimate of the time when life originated on Earth to within the first billion years after the Earth was formed.

STS-6 launched April 4, 1983. A variety of biomedical tests was conducted including examinations of fluid shifts, vestibular performance, and visual acuity.

STS-7 launched June 18, 1983. First flight of an American woman astronaut. Tests included inflight physiological monitoring exercise evaluations, and cardiovascular and vestibular studies.

STS-8 launched August 30, 1983. First flight of rats on the Space Shuttle during the equipment verification test of the Animal Enclosure Module designed for use on the Orbiter middeck. Twenty-three medical DTO's were conducted spanning all major areas of biomedical concern.

STS-9 launched November 28, 1983. First flight of Spacelab. First flight of Life Sciences Payload Specialist. Sixteen life sciences experiments were conducted by U.S. and European investigators in radiobiology, circadian rhythms, plant physiology, neurovestibular physiology, metabolism, mass discrimination, endocrinology, cardiovascular physiology, cell biology, immunology, and equipment verification.

1984

Life Sciences Division released second Announcement of Opportunity, AO Number OSSA-2-84, to formally solicit research proposals in the life sciences for conduct in space over the next decade.

Life Sciences Division began focused effort of preparation for Space Station.

Investigations were selected from the Gravitational Biology Dear Colleague Letter for implementation in space.

Nucleic acid polymers in the biological size range were synthesized in a non-random manner, under geologically plausible conditions by Exobiology researchers.

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Flight Programs Branch developed inventory of over 70 items of Life Sciences Laboratory Equipment (LSLE) for use in space.

Flight Programs Branch began international negotiations for NASA life sciences experiments on European and Japanese Spacelab missions.

Flight Programs Branch instituted Flight Sample Bank program to gain maximum return from life sciences flight experiments and to provide a vehicle to broaden life sciences community participation in space flight efforts.

Shuttle flight 41-B launched February 3, 1984. DTOs addressed vestibular and cardiovascular problems.

Shuttle flight 41-C launched April 6, 1984. Carried Shuttle Student Involvement Experiment on arthritic rats in Animal Enclosure Module. DTOs examined vestibular function and countermeasures to cardiovascular deconditioning.

Shuttle flight 41-D launched August 30, 1984. Flight test of autogenic feedback training hardware and protocols. Medical DTOs conducted in vestibular, cardiovascular, and gastrointestinal areas.

Shuttle flight 41-G launched August 5, 1984. This flight carried a cooperative NASA-Hungarian experiment to test a Hungarian-developed radiation dosimeter and a Canadian experiment to investigate vestibular disturbances in space as well as medical DTOs.

1985

January-April

Exobiology Program initiated vigorous flight effort to participate in planetary exploration missions, space station experiments, and orbiting observatories.

Biospherics Research Program completed first methane mapping of Florida Everglades by orbiting satellites.

Flight Programs initiated Small Payloads Program.

Shuttle flight 51-D launched April 12, 1985. Extensive biomedical tests conducted on Payload Specialist Senator E. J. Garn. Tests included the flight of the American Flight Echocardiograph.

Shuttle flight 51-B launched April 19, 1985. Represents the largest flight of animals in space flight history. Twenty-four rats and two squirrel monkeys were flown as part of the equipment verification test of the LSLE Research Animal Holding Facility. Studies of these animals postflight revealed significant changes as a result of space flight. Other LSLE equipment verification tests included the Urine Monitoring System, Dynamic Environment Measurement System, and Biotelemetry System. *Spacelab 3* also carried the Autogenic Feedback Training Experiment as a test of a possible countermeasure to space motion sickness. Successful proof-of-concept test of the Flight Sample Bank was completed.

APPENDIX 2
Research Project Selection and Review Process

NASA centers and the research community contribute in various ways to the Life Sciences Program. The work is done by NASA scientists, guest investigators, and contractors and ranges from applied to basic in nature. The in-house program amounts to about 40 percent of the Life Sciences budget. The remainder of the research is done primarily by university, research institute, and industrial scientists. Both in-house and extramural research is peer-reviewed by panels of impartial scientists selected and convened by such organizations as The American Institute of Biological Sciences (AIBS) or The Federation of American Societies for Experimental Biology (FASEB). Special studies of specific areas of research are also reviewed by these organizations. Each research proposal is reviewed for scientific excellence and relatedness to NASA objectives and given a numerical rating for scientific excellence. Based on the numerical rating and on the relevance of the work, NASA officials select research for funding.

All ongoing research is reviewed annually. This process of rigorous and continuous review has produced a stable and productive program of basic and applied research in the life sciences (Figures 52A & 52B).

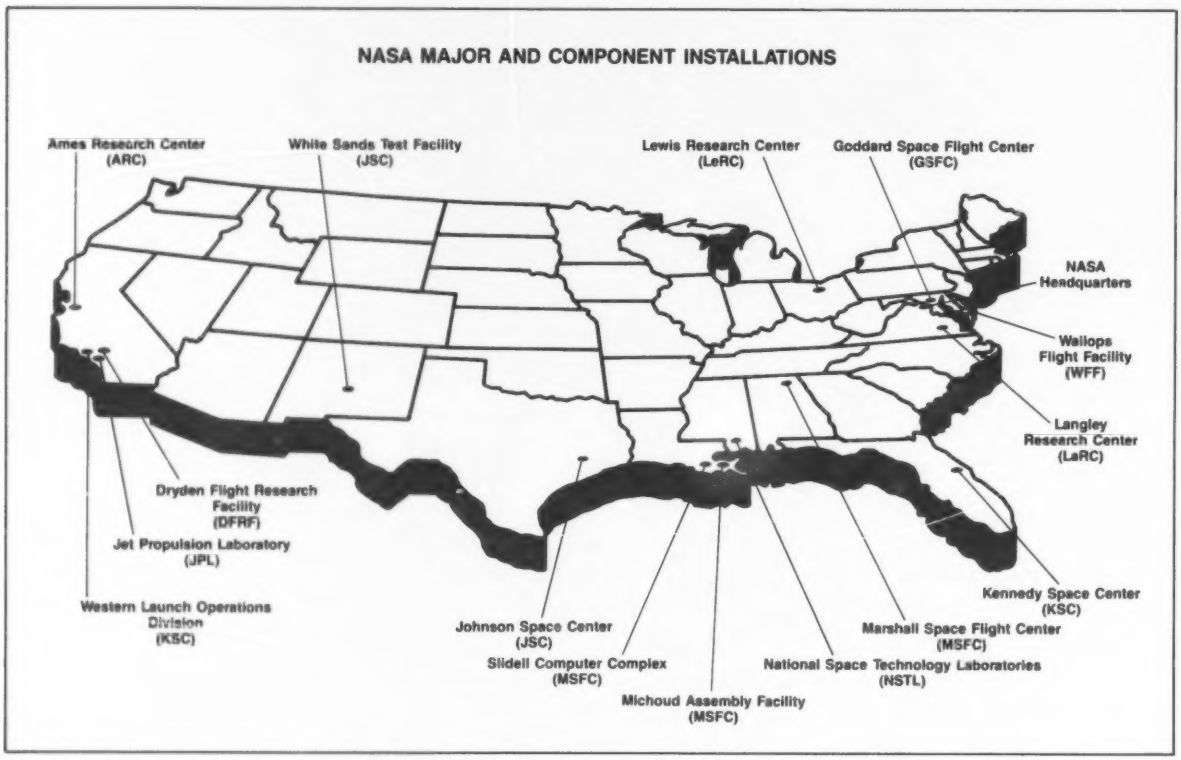
NASA MAJOR AND COMPONENT INSTALLATIONS
Ames Research Center (ARC)
White Sands Test Facility (JSC)
Lewis Research Center (LeRC)
Goddard Space Flight Center (GSFC)
NASA Headquarters
Wallops Flight Facility (WFF)
Langley Research Center (LaRC)
Dryden Flight Research Facility (DFRF)
Jet Propulsion Laboratory (JPL)
Western Launch Operations Division (KSC)
Johnson Space Center (JSC)
Slidell Computer Complex (MSFC)
Michoud Assembly Facility (MSFC)
National Space Technology Laboratories (NSTL)
Marshall Space Flight Center (MSFC)
Kennedy Space Center (KSC)

Figure 52A. *NASA Major and Component Installations*

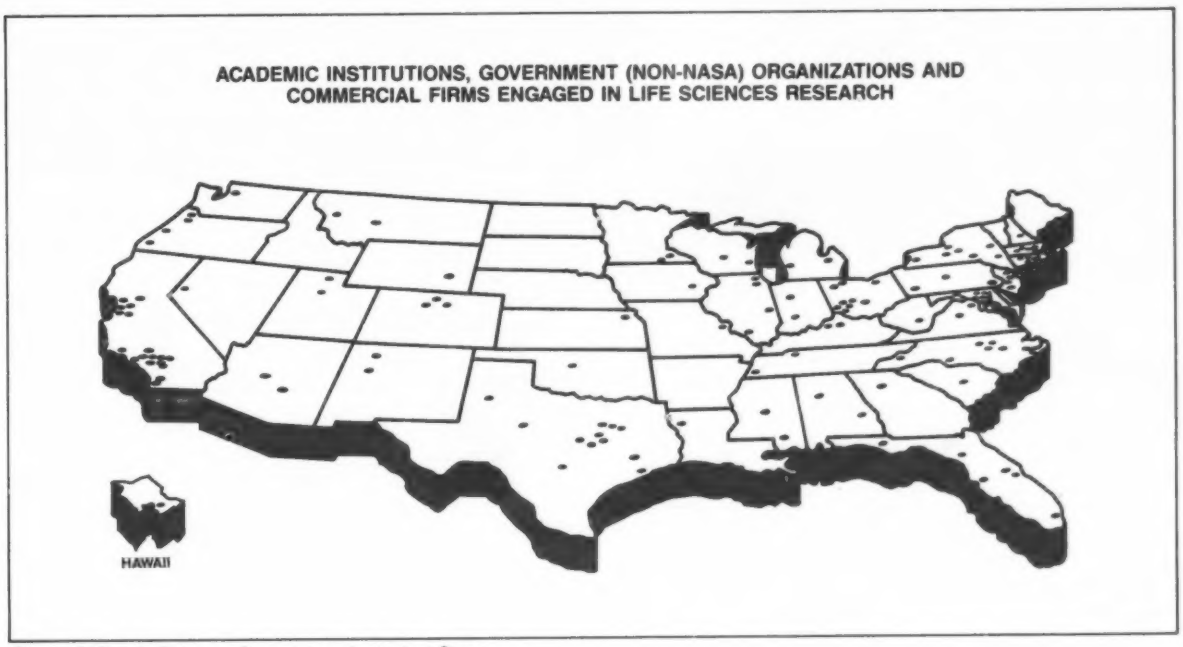
ACADEMIC INSTITUTIONS, GOVERNMENT (NON-NASA) ORGANIZATIONS AND
COMMERCIAL FIRMS ENGAGED IN LIFE SCIENCES RESEARCH
HAWAII

Figure 52B. *Life Sciences Research in the United States*

Life Sciences Research in the United States

This listing includes some U.S. government organization, academic and research institutions, and commercial-industrial firms conductng NASA life sciences research. Refer to map for geographical locations.

ALABAMA
University of Alabama
Tuskegee Institute

ARIZONA
Arizona State Univeristy
University of Arizona

CALIFORNIA
Veterans Administration Medical Center
University of California - branches at:
Berkeley
Davis
Irvine
La Jolla
Los Angeles
Northridge
Riverside
San Francisco
Santa Barbara
Linus Pauling Institute
University of Southern California School of Medicine
Molecular Research Institute
California Institute of Technology
California State University
University of California Medical Center
San Diego State University
Salk Institute for Biological Studies
University of the Pacific
University of San Francisco
San Francisco State University
San Jose State University
University of Santa Clara
Stanford University
Joint Sciences Center
Rockwell International
SRI International
Medical Corporation

COLORADO
University of Colorado - branches at:
Boulder
Denver
Colorado State University

CONNECTICUT
Naval Submarine Medical Research Laboratory
Yale University
Springborn Laboratories
Hamilton Standard

DELAWARE
College of Marine Studies

DISTRICT OF COLUMBIA
Armed Forces Institute of Pathology
Library of Congress
Howard University
Management and Technical Services Company
Aerospace Medical Association
American Institute of Biological Sciences (AIBS)

FLORIDA
Veterans Administration Medical Center
University of Miami
University of Florida
University of South Florida
Florida State University
Florida A&M University
Bionetics Corporation
Essex Corporation

GEORGIA
Emory University
Georgia Institute of Technology

HAWAII
University of Hawaii, Manoa

ILLINOIS
Argonne National Laboratory
Southern Illinois University
University of Chicago
University of Illinois
Rush Medical College
Northwestern University
University of Illinois

INDIANA
Indiana University
Purdue University

IOWA
University of Iowa

KANSAS
Kansas State University

KENTUCKY
University of Kentucky
University of Louisville

LOUISIANA
Tulane University
Louisiana State University

MARYLAND
Federation of American Societies for Experimental Biology (FASEB)
Johns Hopkins University
University of Maryland - branches at:
- Baltimore
- College Park

Martin-Marietta Labs
Beltsville Human Nutrition Research Center
National Center on Radiation Protection & Measurement
Universities Space Research Association
Exotech Research and Analysis

MASSACHUSETTS
Amherst College
University of Massachusetts
Boston University
Bridgewater State College
Harvard University
Massachusetts Institute of Technology
Tufts University
Harvard Medical School
Baystate Medical School
Brandeis University
Woods Hole Oceanographic Institution
Modar, Inc.

MICHIGAN
University of Michigan
Hope College

MINNESOTA
Mayo Clinic

MISSISSIPPI
University of Mississippi
National Space Technical Labs

MISSOURI
Washington University
St. Louis University

MONTANA
Montana State University

NEVADA
University of Nevada

NEW HAMPSHIRE
University of New Hampshire

NEW JERSEY
University of Medicine & Dentistry of New Jersey
Fairleigh Dickinson University
Columbia Scientific, Inc.
Medical Association, Inc.

NEW MEXICO
University of New Mexico
Los Alamos Scientific Laboratory
Lovelace Medical Foundation

NEW YORK
State University of New York - branches at:
- Albany
- Binghamton
- Brooklyn
- Buffalo
- Stony Brook

Brooklyn College
Veteran's Administration Medical Center
Polytechnic Institute of New York
Cornell University
Rockefeller University
Mt. Sinai School of Medicine
Columbia University
New York University Medical Center
Beth Israel Medical Center
State University Hospital
Rensselaer Polytechnic Institute
Brookhaven National Laboratory

NORTH CAROLINA
University of North Carolina
Western Carolina University
Duke University
North Carolina State University
Wake Forest University

OHIO
Wright Patterson Air Force Base
Bowling Green State University
University of Cincinnati
Case Western Reserve University
Ohio State University
Wright State University
Miami University
University of Toledo
Clinical Radiology Testing Laboratory

OKLAHOMA
University of Oklahoma

OREGON
Oregon Graduate Center
University of Oregon
Good Samaritan Hospital

PENNSYLVANIA
University of Pennsylvania
Thomas Jefferson University
Drexel University
Hahnemann University
Temple University
University of City Science Center
University of Pittsburgh
Pennsylvania State University

SOUTH CAROLINA
University of South Carolina

TENNESSEE
University of Tennessee
Vanderbilt University

TEXAS
U.S. Air Force School of Aerospace Medicine
Hardin-Simmons University
Texas College of Osteopathic Medicine
Southwestern Medical School
University of Houston
Baylor College of Medicine
Texas Medical Center
Texas Research Institute of Mental Science
Texas Technological University
University of Texas - branches at:
- San Antonio
- Houston
- Galveston
- Austin
- Dallas

Baylor University
Phyto Resource Research, Inc.
Spectrix Corporation
Technology, Inc.
Austin & Associates Clinical Psychology

UTAH
Utah State University
University of Utah

VIRGINIA
Virginia Polytechnic Institute
University of Virginia
Eastern Virginia Medical School
Virginia Commonwealth University
Veteran's Administration Medical Center
Advanced Technology, Inc.

WASHINGTON
University of Washington
Veteran's Administration Medical Center

WEST VIRGINIA
West Virginia School of Osteopathic Medicine

WISCONSIN
University of Wisconsin
Medical Science Center
Marquette University
Medical College of Wisconsin

WYOMING
University of Wyoming

APPENDIX 3
Training Programs

As plans and preparations are underway to extend time spent living and working in space, the study of space medicine and space biology becomes increasingly important. Research in these vital areas in turn depends on the availability of a trained cadre of scientists and investigators able to find answers to those questions relevant to extending human ability to survive and perform productively in space.

With this need in mind, NASA has established a substantial variety of educational and training opportunities to attract and retain qualified researchers and students working in fields pertinent to its ongoing program of space exploration, especially in space medicine and biology. Listed below are brief highlights of some training programs funded and administered wholly or in part by NASA's Life Sciences Division.

Resident Research Associate Program

Several training opportunities have been established for researchers at the graduate and postgraduate level. First among these is the Resident Research Associate Program (RRA), a postdoctoral program conducted cooperatively with NASA by the National Research Council. Outstanding scientists and engineers from the United States and foreign countries participate in national competition for grant awards which permit them to work as guest investigators at NASA's Ames Research Center, Jet Propulsion Laboratory, or the Johnson Space Center. Selections are made from applicants who choose a research problem of interest to them and compatible with research goals at the three sponsoring laboratories. Awards are for a one-year period, may be renewed, and are designated as either Regular Research Associateships (for persons who have held the doctorate less than 5 years) or Senior Research Associates (for researchers who have held the doctorate more than 5 years).

Aerospace Medicine Resident Program

The Aerospace Medicine Resident Program, a two-year residency, involves participation in medical operations activities and ongoing research in aerospace physiology and medicine at Wright State University School of Medicine, Dayton, Ohio. Research is carried out in conjunction with the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base and involves a third-year rotation through a NASA Research Center.

Space Biology Research Associate Program

Space biology is the principal focus of a research associate program available to scientists in that field who have Ph.D., D.Sc., M.D., D.D.S. or D.V.M. degrees. Program applicants must be U.S. citizens. Specific independent projects of the individual awardees' design are conducted at university laboratories or facilities of their choice. Proposals submitted by applicants are evaluated on scientific merit, and awards are made in January and June for one-year periods, with the possibility of renewal.

Planetary Biology Intern Program

Graduate students in selected fields related to planetary biology have the opportunity to participate in an intern program of research conducted at various universities and NASA centers. Interns chosen will participate in research activities with a NASA-sponsored investigator during eight-week summer periods. Those eligible to apply are graduate students and senior undergraduates majoring in biology, paleontology, atmospheric sciences, and geochemistry.

Space Life Sciences Training Program

One facet of NASA's training effort specifically involves college undergraduates interested in space life sciences, space medicine, and space bioengineering. Participants prepare actual Shuttle-borne flight experiments during an intensive six-week summer program at the Kennedy Space Center and receive five semester credit hours without charge. Applicants must be U.S. citizens who have completed one year of college with at least a 3.0 GPA. Student participation at Florida colleges and universities will be emphasized, and minority participation is especially encouraged. The end result of this pilot effort should be a pool of talent in universities, industry, and NASA who have gained practical experience in space flight through participation in this program.

APPENDIX 4
International Agreements

I. Ongoing Agreements and Memoranda of Understanding (MOU)

1. CNES (France)/NASA. Life Sciences Working Group - meets twice yearly (Senior Managers) to discuss joint special collaborative (Figure 53A) programs, experiments and/or hardware.

2. U.S.S.R./NASA - Cosmos flight experiment series

3. DFVLR (Germany)/NASA - Life Sciences Working Group - meets twice yearly (Senior Managers) to discuss joint special collaborative programs. Experiments and/or hardware.

4. Canada/NASA - MOU. Relates to Space Adaptation Syndrome and Depth Perception experiments.

5. UK/NASA - Joint experiments to fly on the International Microgravity Laboratory (IML) Spacelab in response to a 1978 Announcement of Opportunity.

6. Australia/NASA - Joint experiments to fly on SLS-2.

7. Switzerland/NASA - Joint experiments to fly on SLS-1.

8. ESA/NASA - Joint experiments to fly on IML-1 - Life Sciences and Materials Processing.

9. DFVLR-ESA/NASA - NASA Life Sciences Experiments on the German D-1 mission.

10. NASDA (Japan) NASA - Spacelab - J (1/88). Japanese use of NASA Life Sciences Hardware and some NASA Life Sciences experiments on Spacelab J mission.

Figure 53A. *NASA/CNES Emblem*

II. Agreements Pending

11. NASDA (Japan) NASA - Life Science Working Group to discuss joint collaborative programs.

12. DFVLR-ESA/NASA - NASA Life Sciences Experiment sharing German/ESA Experiment Hardware on German D-2 mission.

13. India/NASA - to fly an Indian Payload Specialist to conduct Indian Life Science experiments in 1986.

14. Israel/NASA - to fly Hornet Experiment.

III. Agreements - Completed

15. Hungary/NASA - Radiation Experiment: 1985 - Shuttle.

16. France/NASA - French Payload Specialist - 1985.

17. Italy/NASA - Otolith Experiment - early 1970s.

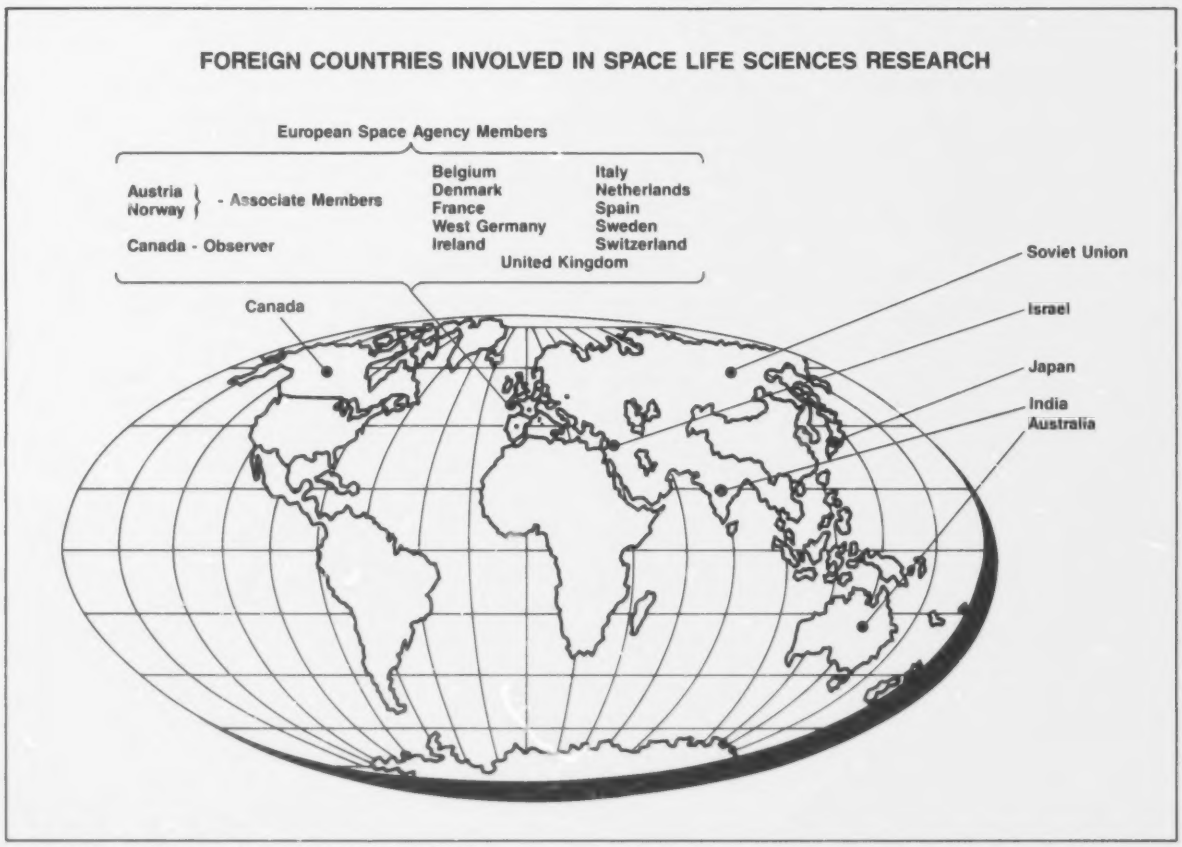

Figure 53B. *Life Sciences Research around the World*

APPENDIX 5
Life Sciences Experiments Flight Schedules

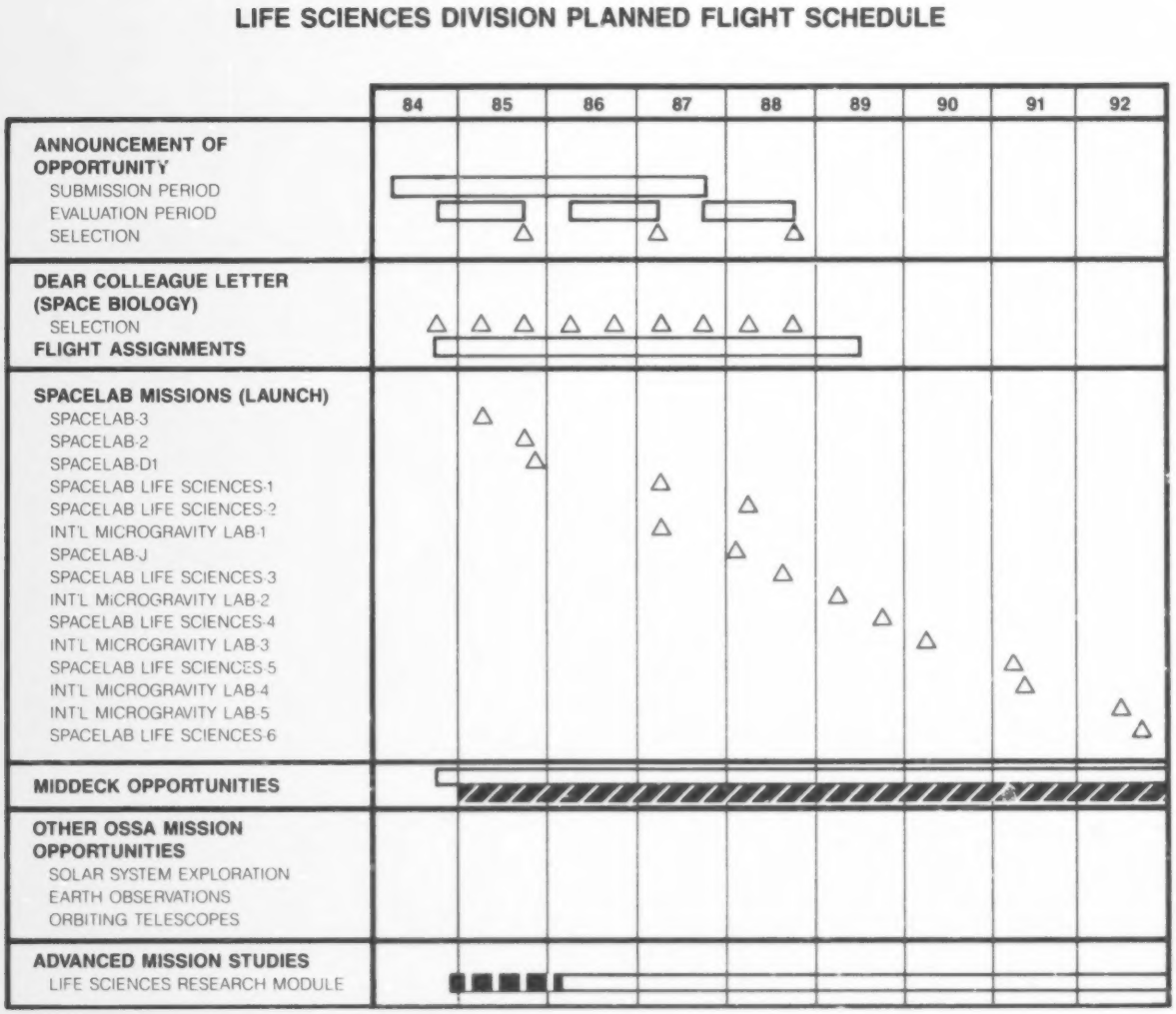

Figure 54. *Life Sciences Division Flight Schedule*

APPENDIX 6
Spin-Offs — Earth Benefits From Space Life Sciences

When Congress passed the Space Act of 1958, establishing the National Aeronautics and Space Administration, Congress specifically declared that one function of NASA is to "provide for the widest applicable and appropriate dissemination of information concerning its activities and the results thereof."

To meet the goals of space exploration and aeronautical development, NASA and its contractors have produced innovations in virtually every field of science and technology. This storehouse of knowledge provides an extremely broad technical foundation for spin-offs — technologies transferred to uses different than and often remote from their original application.

From NASA Life Sciences research, spin-offs result from the two principal elements of the Life Sciences Program. The first is the very practical and applied work related to maintaining the health and safety of humans in the space environment. In achieving a better understanding of the biomedical problems of space flight and in developing countermeasures to these problems, Life Sciences immediately contributes to the solution of terrestrial problems of the same nature. Similarly, new techniques and instruments developed for space medicine quickly find their way into ground-based hospitals and research institutions.

The second principal element of the Life Sciences Division is related to spin-offs from basic research in the biological sciences. Contributions from basic research to the solution of specific human problems is sometimes difficult to describe because of the type of approach used to solve a particular problem. The problem of bone demineralization illustrates the process.

We know that bone demineralization from space flight can lead to less dense ones which are more susceptible to fracture — a problem very similar to osteoporosis, which afflicts the elderly on Earth. There are two major approaches that will help solve the bone demineralization problem. We can learn to use surgical or drug procedures to counter the condition, or we can learn to prevent it from occurring. These are very direct and applied techniques.

However, many scientists look at bone physiology from a different perspective — they may seek very basic knowledge about how bone cells grow and function, and what makes bone function abnormally. Cell biologists may have no direct ties with the medical community that is specifically seeking to combat the problem, but the efforts of researchers devoted to understanding the very nature of bone cell physiology offer our only hope of understanding demineralization — its causes and cures. It is by applying the knowledge gained and technology developed through basic research that we produce the surgical techniques, drug treatments, and preventive practices that solve many medical problems.

From the earliest days of the manned space program, NASA has developed and used telemetry to monitor electrocardiograms (EKGs) and other vital signs of astronauts during flight. These data were used to assure mission controllers on the ground that astronauts remained healthy throughout the flight and to provide research data to understand the

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effects of weightlessness on crew health and performance. Modern health care systems now routinely use much of this technology to provide better medical care to patients on Earth.

The combination of electronic medical monitoring systems and communication, via conventional ground-based telemetry and satellites, has been effective in improving health care services in urban and remote locations. Referred to as telemedicine, it augments existing health care delivery systems by providing a direct link between remote paramedic personnel working with the patient and experienced physicians at a central location.

In planetary exploration, many images of planets, satellites, and rings have been computer-enhanced to reveal details not obvious in the initial picture (Figure 55). For almost two decades, this same computer processing has been used in medicine. The two areas of application are in images obtained from light microscopes and in x-ray images.

Initial efforts at automated light microscopy were developed at NASA's Jet Propulsion Laboratory for use during the Viking lander mission to Mars, where the technique was used to search for existence of life forms. In x-ray image analysis, computer processing is currently being developed at JPL to allow noninvasive analysis of cardiovascular function at lower x-ray doses.

Other spin-offs include voice-controlled wheelchairs for severely handicapped people, reading machines for the blind, new flame-resistant materials, emergency lighting systems, solar cell-powered air monitoring systems, medication delivery systems implanted into patients to deliver precisely controlled amounts of drugs at designated intervals, among many others. In fact, there are so many spin-offs from space technology, that each year NASA publishes a special document describing them so the public knows these resources are available and that they can use the capabilities offered by spin-off technology. (Please refer to the additional reading list presented in Appendix 7 for further information.)

Figure 55.
Computer Enhancement Technology

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APPENDIX 7
Additional Reading

The following documents were selected from a more extensive listing to provide more details about and support for many of the programs summarized in this report. The listing is not intended to be complete, but rather to identify key references.

First Symposium on Chemical Evolution and the Origin of Life, D.L. DeVincenzi and L. Pleasant, Editors, NASA Conference Publication 2276, 1983.

Foundations of Space Biology and Medicine, Joint U.S.A./U.S.S.R. publications, Vol. I-III, M. Calvin and O. G. Gazenko, Editors, NASA and U.S.S.R. Academy of Sciences, 1975.

Future Directions for the Life Sciences in NASA, Life Sciences Advisory Committee, NASA Advisory Council, Washington, D.C., 1978.

Global Biology Research Program, Program Plan, NASA TM 85629, January 1983.

Global Change: A Biogeochemical Perspective, Michael McElroy, Workshop Chairman, NASA, JPL Publication 83-51, 1983.

Global Change: Impacts on Habitability, Woods Hole Workshop, Richard Goody, Chairman, NASA, JPL D-95, 1982.

Human Behavior in Space Environments: A Research Agenda. J. Brady, Johns Hopkins University Press, Baltimore, MD, 1983.

Life Beyond the Earth's Environment, National Academy of Sciences, Space Science Board, 1979.

Life in the Universe, J. Billingham, Editor, MIT Press, 1981.

Life Sciences — a Strategy for the 80s, P.C. Rambaut and D.L. DeVincenzi, Life Sciences Division NASA Headquarters, Washington, D.C., September, 1984.

Life Sciences Investigations in Space, 1985-1991, Announcement of Opportunity, NASA, Washington, D.C., May 15, 1984.

Origin and Evolution of Life — Implications for the Planets: a scientific strategy for the 1980s, National Academy of Sciences, Space Science Board, 1981.

Planetary Exploration Through the Year 2000, Solar System Exploration Committee, NASA Advisory Council, Washington, D.C., 1983.

Radiation Protection for Manned Space Activities, T.M. Jordan, NASA Jet Propulsion Laboratory, Pasadena, CA, 1983, JPL Publication 83-26.

Research Opportunities in Bone Demineralization, S.A. Anderson and S.H. Cohn, Editors, Federation of American Societies for Experimental Biology, Bethesda, MD, 1983, NASA Contractor Report 3795.

Research Opportunities in Cardiovascular Deconditioning, M.N. Levy and J.M. Talbot, Editors, Federation of American Societies for Experimental Biology, Bethesda, MD, 1983, NASA Contractor Report 3707.

Research Opportunities in Muscle Atrophy, G.J. Herbison and J.M. Talbot, Editors, Federation of American Societies for Experimental Biology, Bethesda, MD, 1984, NASA Contractor Report 3796.

Research Opportunities in Space Motion Sickness, J.M. Talbot, Editor, Federation of American Societies for Experimental Biology, Bethesda, MD, 1983, NASA Contractor Report 3708.

SETI Science Working Group Report, F. Drake, J. Wolfe, and C. Seeger, Editors, NASA, 1983.

Space Biology, National Academy of Sciences, Space Science Board, 1978.

Space Science and Applications Notice, Emerging Opportunities in the Space Biology Program, September 1983.

Space Physiology and Medicine, A. E. Nicogossian and J. F. Parker, Jr., NASA SP-447, 1982.

Spinoff 1984, James J. Haggerty, NASA, July 1984.

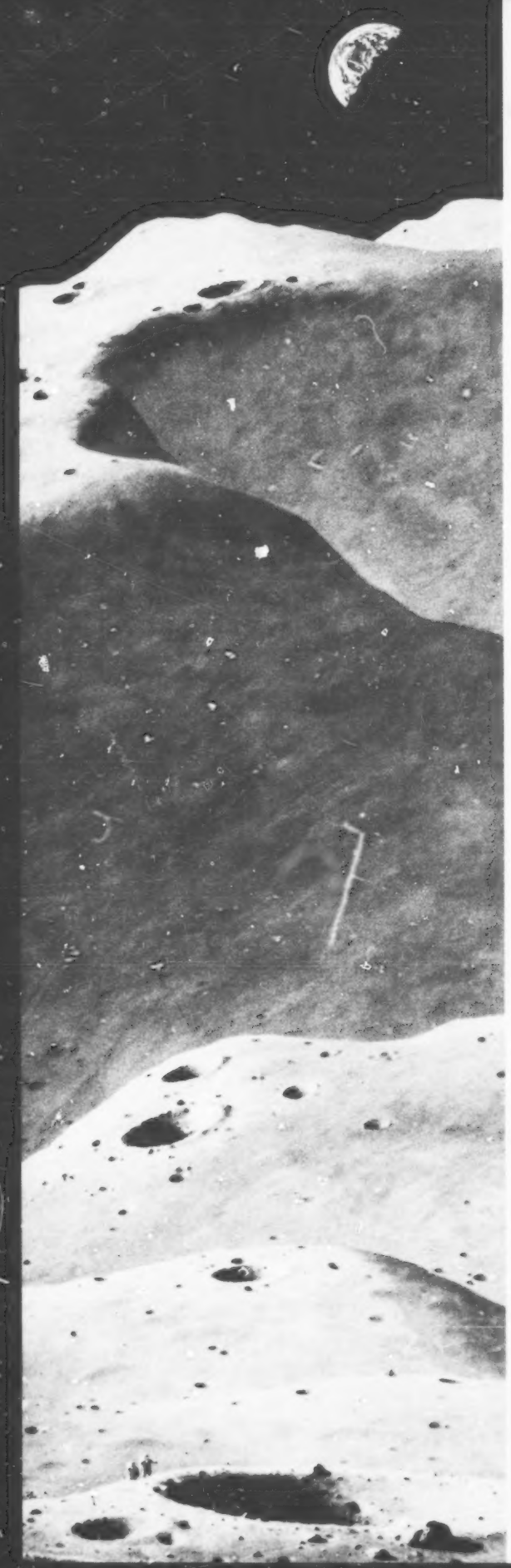

Figure 56.
Astronauts Explore the Moon
NASA Artist: Pierre Mion

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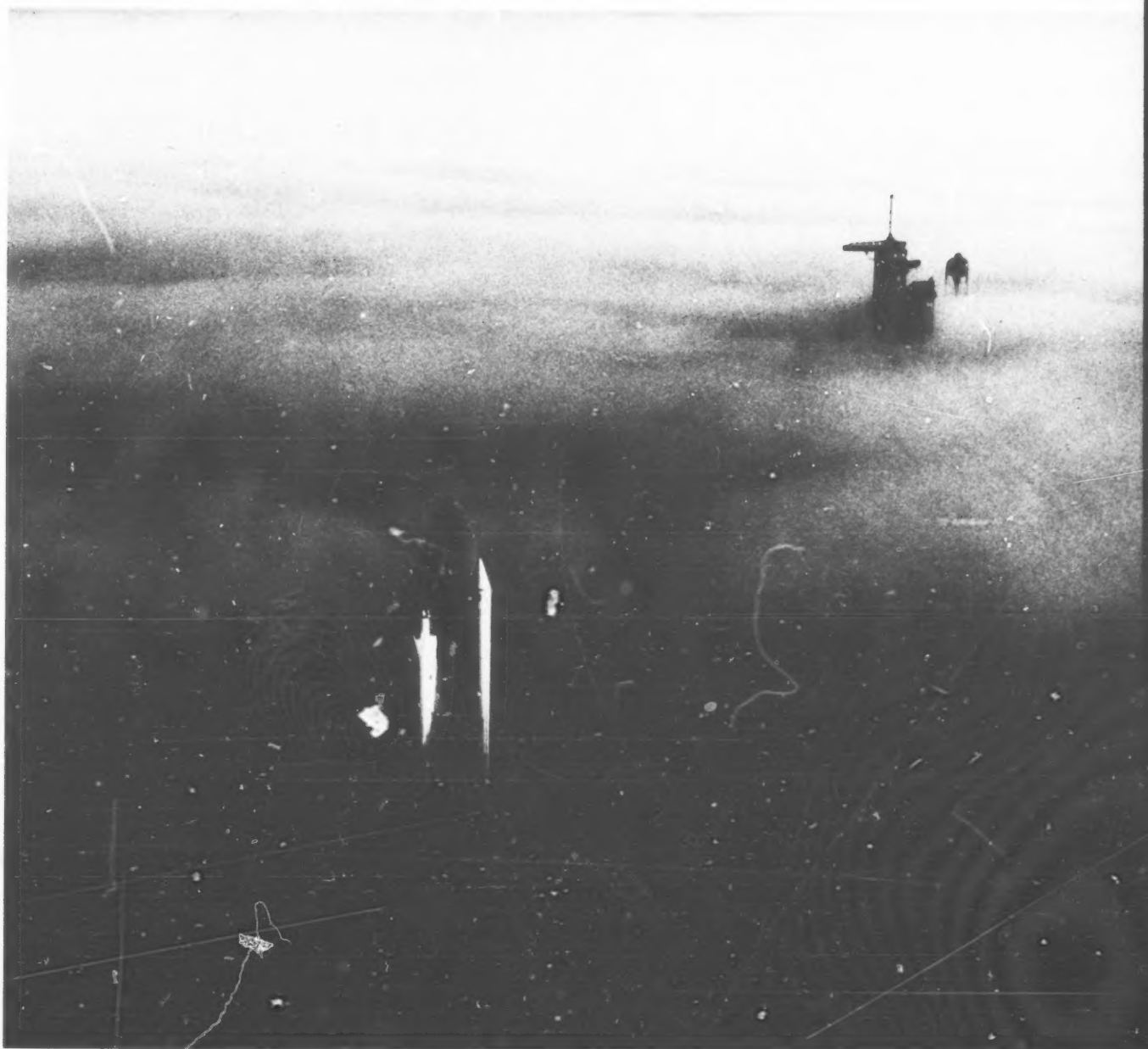

Figure 57. *Shrouded in early morning mists, a Shuttle on its crawler transport vehicle slowly trundles toward the launch pad, where it will be sent on a rendezvous with space.*

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unless otherwise credited.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-88177		

4. Title and Subtitle	5. Report Date
Life Sciences Accomplishments	September 1985
	6. Performing Organization Code: EB

7. Author(s)	8. Performing Organization Report No.
	10. Work Unit No.

9. Performing Organization Name and Address	11. Contract or Grant No.
Office of Space Science and Applications Life Sciences Division Code EB Washington, D.C. 20546	13. Type of Report and Period Covered: Technical Memorandum

12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Washington, D.C. 20546	

15. Supplementary Notes

16. Abstract

From its inception, the main charter of Life Sciences has been to define biomedical requirements for the design and development of spacecraft systems and to participate in NASA's scientific exploration of the universe. The role of the Life Sciences Division is to:

1. Assure the health, well-being and productivity of all individuals who fly in space;
2. Study the origin, evolution, and distribution of life in the universe; and
3. To utilize the space environment as a tool for research in biology and medicine.

This report details the activities, programs, and accomplishments to date in our efforts to achieve these goals and examines the future challenges that face the Division as we move forward from the Shuttle era to a permanent manned presence in space — Space Station.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Life Sciences Flight Experiments Program Space Medicine Biomedical Research Biospherics Research Spaceflight	Unclassified - Unlimited Subject Category 51

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

N-305

For sale by the National Technical Information Service, Springfield, Virginia 22161